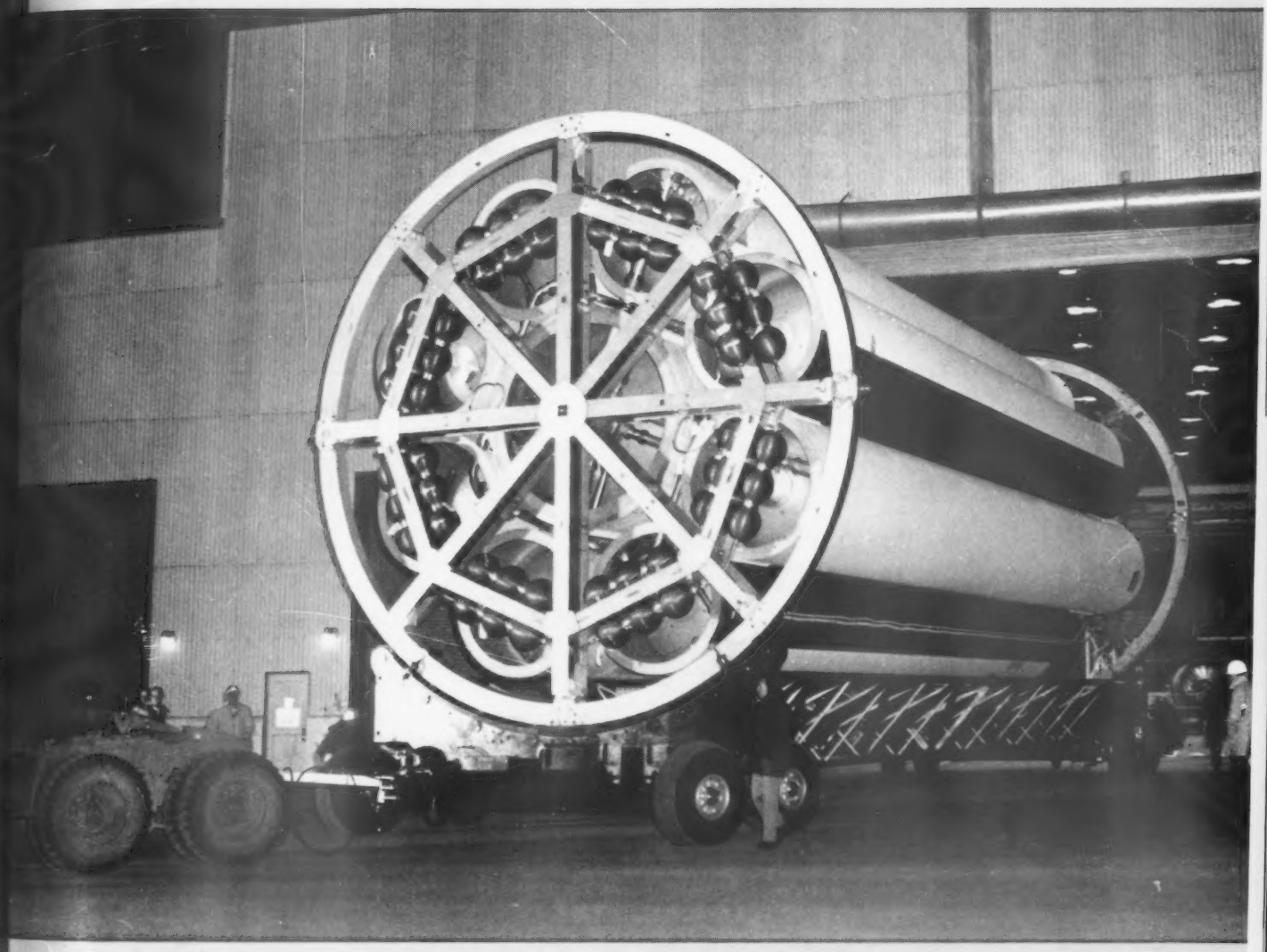
SPACE EXPLORATIO. ISSUE

Spaceflight

OF MICHIGAN
JUN 2[illegible] 1960
ENGINEERING LIBRARY



VOL. II No. 7

CONTENTS

JULY 1960

	Page
THE EXPLORATION OF OUTER SPACE. A. C. B. Lovell	194
SPACEFLIGHT AT THE PLANETARIUM	203
SKYLARK. Maurice Allward	204
EXPLORATION OF THE MOON:	
1. THE LUNAR OBJECTIVE. Patrick Moore	209
2. THE ROBOT EXPLORERS. K. W. Gatland	212
3. MAN ON THE MOON. W. N. Neat	219

PRICE 3/6

PUBLISHED BY THE BRITISH INTERPLANETARY SOCIETY

Plans and projects for interplanetary travel and colonization, from Mercury to Pluto . . .

THE EXPLORATION OF THE SOLAR SYSTEM

by

Felix Godwin

This fascinating book, which has received a whole-hearted commendation from the Astrophysical Observatory of the Smithsonian Institution, outlines the development of astronautics during the next 150 years. Actual expeditions have been described in detail to demonstrate how the problems of space travel can be overcome with the equipment available or now being planned. The author has considered the landing on another world not as an end in itself but as a means of making new discoveries in geophysics and other branches of science. For this reason a large part of the book has been devoted to considering what space explorers will do when they arrive, apart from how they will get there.

200 pages · 22 diagrams · 10 plates · 35s. net

CHAPMAN & HALL · 37 ESSEX STREET · LONDON, W.C.2

INTERPLANETARY PUBLISHING CO.

12 BESSBOROUGH GARDENS · S.W.1

Forthcoming Books

International Missile and Spacecraft Guide. Ordway & Wakeford. May. 550 pp. 861 illus. about **93/-**

This book, by members of the National Research and Development Center, is a comprehensive review of all significant rockets, missiles and spacecraft which have been designed and produced during the last fifty years. It is an exceptionally complete picture of the development of the missile as a military weapon and research tool, and it presents the technical details of the research and test vehicles which preceded modern rockets.

Missile Aerodynamics. Nielsen. April. 335 pp. about **62/-**

It discusses the subjects of bodies, wings and the interactions between them which are particularly important for missiles and presents a rational and connected account of the principles of missile aerodynamics. Various methods are presented for determining the air flow around missiles, and full account is given of the drag of missiles.

Propulsion Systems for Space Flight. Corliss. May. 350 pp. 150 illus. about **77/6**

Propulsion systems such as the nuclear rocket, ion drives, photon drives and anti-gravity devices are compared in terms of performance capability, technical feasibility and present state of development. Power and propulsion systems are treated to strict scientific analysis, and assigned to their proper places in space technology.

New Astronomical Publications

Guide to the Stars	Moore.	256 pp.	16 plates.	40 diags.	**21/-**
Moon Maps (With a Chart showing the Other Side of the Moon, based upon the Soviet Photographs)	Wilkins.	36 pp.	27 plates.		**30/-**
The Sun	Severny.	173 pp.			**5/-**
Vistas in Astronomy, Vol. III.	Beer Ed.	200 pp.			**84/-**

SPACEFLIGHT

Volume II July 1960 Number 7

Editor
KENNETH W. GATLAND, F.R.A.S.

Editorial Board
M. F. ALLWARD
C. A. CROSS, M.A., F.R.A.S.
D. HURDEN, B.A., GRAD. I. MECH. E.
A. E. SLATER, M.A., M.R.C.S., L.R.C.P., F.R.MET.S., F.Z.S.

Correspondence and manuscripts intended for publication should be addressed to the Editor at 42, Knightwood Crescent, New Malden, Surrey.

Opinions in signed articles are those of contributors, and do not necessarily reflect the views of the Editor, the Editorial Board or the Council of the British Interplanetary Society, unless such is expressly stated to be the case.

All material is protected by copyright. Responsibility for security clearance, where appropriate, rests with the author.

***Spaceflight* is published quarterly by the British Interplanetary Society, and is issued free to members.**

Full particulars of membership of the British Interplanetary Society may be obtained from the Secretary. The secretarial address is 12, Bessborough Gardens, London, S.W.1; telephone TATe Gallery 9371.

COVER:

America's answer to the giant multi-stage rocket that launched Russia's 10,010-*lb. "satellite-spaceship" on* 15 *May is the Saturn booster of* 1·5 *million lb. static thrust. Here, the eight-engine first-stage leaves the assembly shop at Redstone Arsenal, Alabama, en route for the static test-site. When fully developed, with lox-hydrogen top stages, it will orbit* 25,000 *lb.*

Army Ballistic Missile Agency

A B.I.S. Memorandum

In the May-June issue of the *Journal*, readers will find the full text of a Memorandum on "The Need for a U.K. Space Programme" which the Society submitted to the Prime Minister on 2 March. This document was the outcome of two special confidential meetings convened by the Society on 15 January and 19 February, well before the cancellation of the Blue Streak as a ballistic weapon.

At the time of writing, the outcome of the Government's deliberations on the future of Blue Streak—which was the basis of the Society's satellite proposals—is not known. It can be said, however, that Lord Hailsham, Lord Privy Seal and Minister for Science, received a deputation from the Society on 10 May comprising Dr. L. R. Shepherd (chairman), Mr. A. V. Cleaver (past-chairman), and Mr. Woodrow Wyatt, M.P., when further recommendations were discussed in the light of the Blue Streak situation. These concerned the prospects of the U.K., Australia, and other non-European nations, joining forces with Western Europe in a united programme of aero-space development. In this way, it was felt that the U.K. could place at the disposal of a European project, existing facilities and the background of work on Blue Streak and thereafter, contribute a reasonable proportion of the annual budget for the joint programme.

Two Major Triumphs

Two important events in astronautical science have taken place since the last issue of ***Spaceflight*** appeared. One is the outstanding success of the 98·4-lb. American solar-probe, Pioneer V, in signalling back to Earth information on conditions in space over millions of miles. With this must be linked the use of Jodrell Bank's radio-telescope in long-range space-communications. The other is the considerable Russian triumph in putting into orbit close to the Earth a fully-equipped embryo "spaceship" of 10,010-lb., complete with 2½-ton detachable pressurized cabin, dummy astronaut and oxygen equipment.

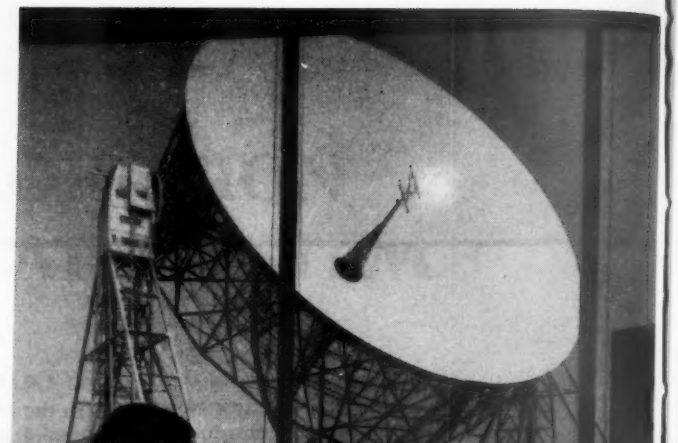
Both experiments are remarkable in their own right. The first has shown the extent to which use can be made of small payloads by ingeniously-designed miniaturized equipment; the second how the development of large rocket boosters is leading to the early arrival of man in space.

However, no-one is likely to suggest that success with the latter will be achieved overnight. An orientation fault deprived Soviet scientists of claiming full success for their experiment (similar troubles have afflicted the American Discoverer programme aimed at the recovery from orbit of a 300-lb. capsule), while the Russians, at least, apparently still consider re-entry into the atmosphere a difficult problem. The Americans, of course, have their own plans for orbiting a man next year in the much smaller one-ton Mercury space-capsule.

PRINTED IN GREAT BRITAIN

The Exploration of Outer Space*

By A. C. B. LOVELL, O.B.E., F.R.S.†



View of the Jodrell Bank radio-telescope from the control desk.

Crown copyright reserved

Introduction

Five years ago on 23 March, 1955, I had the privilege of addressing this Society.‡ The title of my lecture was "Radio Astronomy," in which I described man's new techniques for the exploration of space made possible by the discovery that radio waves were reaching the Earth from outer space. Since the dawn of consciousness man has used his eyes to study the stars in the sky and for the last 300 years the development of the optical telescope has provided him with increasing powers of penetration into the heavens. In the decade before the second World War the great optical telescopes on Mts. Wilson and Palomar in America photographed systems of stars and galaxies from which the light had taken a thousand million years to reach us after its journey through space. It seemed then that man was in possession of the ultimate tool for the exploration of space and that he would soon be able to reach a final decision on the processes of evolution and origin of the cosmos.

During those wonderful years of discovery the astronomers were almost intoxicated by the power of the optical telescope combined with the photographic plate and the spectroscope. Man had been blessed with senses of sight which enabled him to see the light emitted by the stars and galaxies, and although our terrestrial atmosphere was opaque to anything but the colours of the rainbow there was no serious enquiry or anxiety as to the extent of any limitations which this might entail on our knowledge of outer space. However, at the very moment when these telescopes were in the full flood of discovery an American engineer, Karl Jansky, who was investigating thunderstorms with a radio receiver, made a simple observation which was to effect a transformation in the techniques for the investigation of outer space. He found that the background noise in the receiver which should have remained constant if it was all produced in the components of the receiver varied systematically throughout the day. Jansky noticed that this daily variation occurred with a period of 23 hr. 56 min. which is the period of rotation of the Earth with respect to the stars. The elegance of the observation lies in its simplicity and in the unambiguity of the conclusion that whatever was responsible for the daily variation must originate from regions of space outside the solar system. The work encountered all the classic hindrances which nearly always accompany great scientific discoveries, and now it is with incredulity that one reads that Jansky's employers transferred him to other work and that for nearly 10 years interest in the subject was sustained only by the efforts of Grote Reber,

* *The Trueman Wood Lecture delivered before the Royal Society of Arts on 24 February, 1960, and reproduced by kind permission of the Council.*

† *Professor of Radio Astronomy, University of Manchester, and Director of Jodrell Bank Experimental Station.*

‡ *The Royal Society of Arts.*

who built apparatus in his own garden while carrying on full-time occupation in a quite unrelated subject. In fact Jansky and Reber had shown that the light from the stars and nebulae was not the sole means at man's disposal for investigating the cosmos, but that this so-called optical window in the Earth's atmosphere was accompanied by a much more extensive window at longer wavelengths in the radio wave region through which radio waves were reaching the Earth from outer space. The work of these pioneers remained almost unknown and the significance of the discovery was certainly not understood until the technical developments of the war stimulated a few scientists to study the heavens in this region of the spectrum. Now, radio telescopes are almost as common as optical telescopes and astronomy is in the throes of a revolution which can be reasonably compared with that which arose from the investigations of Galileo.

As these technical legacies of one war were being woven into astronomical instruments, the fear of another conflict drove the Great Powers into the expenditure of unprecedented sums of money for the development of ballistic rockets. After 10 years of progress towards purely militaristic ends both the U.S.A. and the U.S.S.R. found themselves possessed of rockets which could not only throw a hydrogen bomb across the Atlantic but if otherwise employed might succeed in the almost fictional dream of placing in orbit an artificial Earth satellite. The dramatic realization of this feat by the U.S.S.R. in October, 1957, was followed by a conflict for supremacy between the U.S.S.R. and U.S.A. on a scale which could scarcely be maintained in the interests of fundamental research. Nevertheless these efforts have provided astronomers with means of conveying their instruments to regions of space where the Earth's atmosphere ceases to influence or absorb the radiations reaching us from the Sun and outer space.

During the span of our own lifetime the possibilities for the exploration of outer space have undergone two transformations, one by virtue of the techniques of Earth-based radio astronomy, and the other through the opportunities offered by satellites and space probes which can carry the instruments of the astronomer in at least a temporary escape from their Earth-bound environment.

Where Does Outer Space Begin?

The Earth is 93 million miles from the Sun, the light from which takes 8½ min. to reach us. The most distant planet Pluto is over three and a half thousand million miles away and light from the Sun takes 5 hr. to reach it. Dimensions of this order define the regions of interplanetary space, which contains the Sun and its family of planets including the Earth and the Moon. Compared with the space of the stars and the galaxies interplanetary space is minute, but for us on Earth it is the beginning of outer space in the sense that the Earth and its environment is a minor partner exerting negligible influence on the conditions in it.

Only a few years ago it was believed that the geophysical environment of the Earth was extremely localized. At the altitudes of a few miles above the Earth at which modern aircraft fly the air is already too attenuated to support life without pressurized cabins. At 70 miles the air is extremely thin by terrestrial standards, but fortunately is still dense enought to burn up most of the meteors which bombard us from interplanetary space. In this region, too, some of the radiations from the Sun are absorbed and have a semi-permanent effect on the basic condition of the air, in that an electrified or ionized region surrounding the Earth is created. These ionospheric regions extend upwards to a few hundred miles with a complex and variable structure. They have a significant effect on our daily lives because it is in these regions that radio waves are reflected to make possible round-the-world radio communications. The point where the uppermost of these regions disappears—say, at 300 or 400 miles—was, until recently, generally believed to be the region where any significant effect of the Earth and its atmosphere vanished.

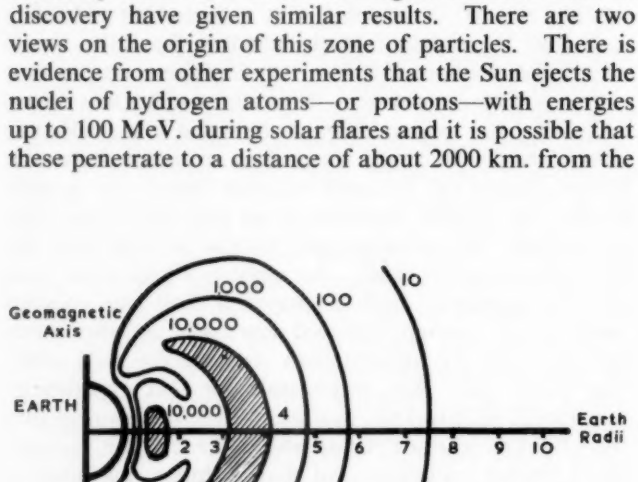
The first and major scientific aim of Earth satellites was to carry instruments to this near region of outer space, and one of the primary desires was to study the solar radiations and other incoming particles and radiations before they were absorbed or otherwise interfered with by the Earth's upper atmosphere. The first successful American satellite, Explorer I (1958), launched in the early hours of 1 February, 1958, contained amongst its instruments a simple geiger counter for the measurement of radiation intensities. This satellite moved in an orbit with a period of 115 min., such that the distance of the satellite from the Earth varied from about 370 km. to 2500 km. during the course of each revolution. When the satellite was below 1000 km., the geiger counter recorded the radiation intensities which might have been expected from the known cosmic ray intensity in outer space. At greater heights the counter behaved in an anomalous way and at 1100 km. the counting rate became so high that the instrument was blocked. An obvious explanation such that the apparatus had developed a fault was rejected because the system behaved normally at the lower altitudes and the phenomenon repeated on each orbit. Van Allen, who was responsible for this experiment, was forced to conclude that as the satellite moved into the 1000 km. altitude region above the Earth it encountered intense radiation, and that within a few hours it was exposed to a dose which would be the limit of human exposure for a whole week. Now this radiation was penetrating the stainless-steel hull of the satellite and the walls of the geiger counter, and van Allen concluded that it could not be electromagnetic radiation but must be corpuscular, probably electrons or protons constrained under the influence of the Earth's magnetic field.

The existence of this intense radiation was confirmed by Explorers III and IV (launched in March and July, 1958), and some information was obtained about the

latitude effects which strengthened the view that the radiation was corpuscular, trapped in the Earth's field. However, the Pioneer deep space probes and the Luniks were required to study the full extent of this radiation belt. The instruments in these probes revealed that yet another zone of radiation existed at a much greater distance from the Earth. Whereas the zone originally encountered by Explorer I was concentrated at a height of about 2000 km., the heart of this outer zone was not reached until the probes had penetrated 20,000 km. into space.

There has been much study in the U.S.A. and the U.S.S.R. of these remarkable discoveries, and although many details remain to be completed it is generally believed that the diagram below gives a reasonable picture of the location of these radiation zones around the Earth. There seems little doubt that the primary constituent of both zones is corpuscular radiation trapped in the Earth's magnetic field, and that they have different origins. At present there seems to be general agreement over the following points.

(*a*) The inner zone probably consists of a penetrating component of protons with energies up to 100 MeV. together with a less penetrating component of electrons up to 1 MeV. The numbers of these particles in the zone are immense compared with anything previously anticipated. Existing figures are that the zone contains 2×10^4 protons/cm.^{2}/sec. with energies greater than 40 MeV., and 2×10^9 electrons/cm.^{2}/sec. with energies exceeding 2 KeV. This radiation zone seems to be relatively stable and all the investigations made since its discovery have given similar results. There are two views on the origin of this zone of particles. There is evidence from other experiments that the Sun ejects the nuclei of hydrogen atoms—or protons—with energies up to 100 MeV. during solar flares and it is possible that these penetrate to a distance of about 2000 km. from the Earth where they come under the predominant influence of the Earth's magnetic field. Another, more popular, view at present is that the protons and electrons in this zone are the products of the decay of a neutron, and that the neutrons responsible are some of the products of nuclear disintegrations produced in the Earth's atmosphere by cosmic ray bombardment. These conflicting views will be settled when more detailed measurements are made of the energy spectrum and life times of the various processes involved.



Intensity of the trapped radiation around the Earth (after Van Allen). This is a cross-section of a 3-dimensional figure of revolution around the Earth's geomagnetic axis. The contours labelled 10,100, etc., are the true counting rates of Geiger tubes carried in Explorer IV and Pioneer III. The horizontal scale is the distance from the centre of the Earth in terms of Earth radii (6371 km.).

(*b*) The outer zone is believed to consist almost exclusively of electrons with an upper energy limit of about 100 KeV. and with something like 10^{11} electrons/cm.^{2}/sec. in the heart of the zone. This zone is very variable and there is no doubt that this variability is closely linked with magnetic storms and solar eruptions. For example, it has been found that a big magnetic storm on the Earth drains the electrons from this zone, and that it is repopulated in a few days, presumably with electrons from the Sun. Cause and effect are not yet distinguished but it is clear that this outer radiation zone is very closely linked with the major geophysical effects observed on Earth, such as magnetic storms and the aurora polaris. It seems that this zone acts in the role of a reservoir of charged particles with the Sun acting as the source and the Earth as the sink.

The energies of the particles in these zones are small compared with the energies of thousands of millions of electron volts with which we are accustomed to deal in cosmic rays and with accelerating machines on Earth. The numbers involved are, however, vast compared with the flux of cosmic ray particles incident on the atmosphere from space—about 2 protons and heavy nuclei/cm.^{2}/sec.; and it is this quantity rather than energy which gives the zones their special importance and, indeed, danger to living organisms. In terms of common radiation dosage cosmic rays represent about 0·01 roentgens/hr., compared with the permissible human dosage of 0·3 roentgens/week. In the heart of the outer radiation zone the dose is about 10 roentgens/hr.—5000 times greater than a human being could stand.

The flight of Pioneer IV in March, 1959, was tracked to 650,000 km. from the Earth before the expiry of its batteries. Beyond 60,000 km. the radiation counters reached a low level corresponding to the cosmic ray background, and although small fluctuations were present there was no significant change over the rest of the journey.

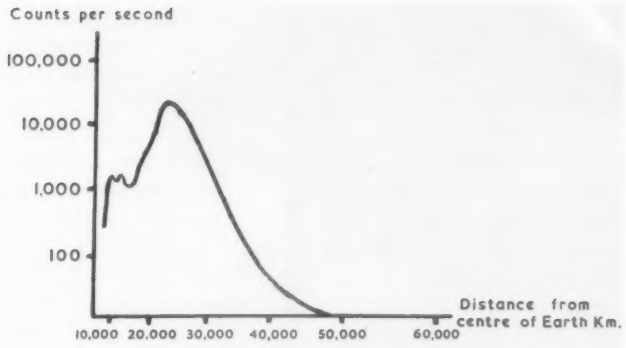
The early experiments with Earth satellites and space probes have yielded a remarkable discovery which is in process of revolutionizing our beliefs about the major geophysical phenomena. Further, they have destroyed the belief that the Earth's physical environment extended only to a few hundred miles. The major influences of the Earth's environment are now set at about 60,000 to 70,000 km. or about 10 Earth radii. It is beyond these regions that outer space can really be said to begin in the sense that the influence of the Sun, planets, stars and galaxies predominate over the terrestrial environment.

The Interplanetary Medium

I suppose that most of us have grown accustomed to the idea that the space between the planets is a vast region of emptiness, and indeed, as judged by terrestrial standards this view is essentially correct. However, during the last few years the scientist has been forced to realize that the simple concept of a Sun, with the Earth and planets moving around it and with little of interest in the intervening interplanetary space, will no longer suffice. The discovery of the radiation belts demonstrated that the Earth's influence exerted a major effect on the interplanetary medium to a distance more than 100 times that assessed from Earth-bound investigations, and it is now a reasonable assumption that the planets, too, will be surrounded by similarly trapped belts of radiation. If, indeed, the major planets like Jupiter, which is eleven times the radius of the Earth and 318 times more massive, has a commensurate magnetic field, then the trapped radiation around it must be very extensive. Here is a major problem for the deep space and planetary probes which will not doubt be launched in the coming years. So far all that can be said is that Lunik II which landed on the Moon on 13 September, 1959, showed that the magnetic field of the Moon, if it existed, must be less than 100 gamma (or 400 times less than the field at the Earth's surface), and that no surrounding radiation belts could be detected. This result is not unexpected.

In the case of the Sun our ideas about its size and influence seem to have increased steadily. It has, of course, been known for many years that the solar atmosphere, or corona, extended far beyond the normally recognized visible disc of the Sun. Until the invention of the coronagraph by Lyot, the corona could be studied only during a solar eclipse and knowledge of it accumulated slowly. The coronagraph gave astronomers the ability to study the corona at will and soon afterwards the discovery that radio waves were emitted by the Sun added still further to the rapid accumulation of knowledge. When the surface of the Sun is disturbed by spots and flares intense radio waves are emitted, but even in its quiet condition radio emissions from the Sun can be detected. These come from the corona, and a strange result has emerged. The size of the Sun depends on the wavelength used by the investigator. By eye we normally see the chromosphere, and the solar radius can be measured as about 700,000 km. If a radio apparatus is used to measure the size, this comes out to be much bigger because the radio waves are emitted from the coronal regions. On a radio wavelength of 10 cm. the Sun is about 1·5 times bigger than the visible disc. At 3 m. it is three times as big and on wavelengths of 8 m. the corona has been estimated to extend to at least ten solar radii.

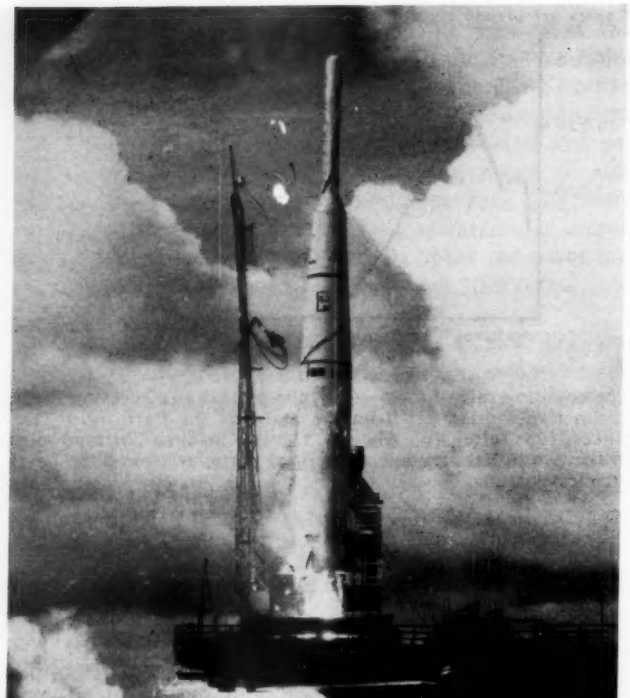
These results have been known for some time, but apart from the intense radiation and the streams of hydrogenous material which are ejected during solar flares it was still believed that we were effectively



The counting rate of the Geiger tube plotted as a function of the distance of Pioneer III from the centre of the Earth on 6 December, 1958 (after Van Allen). The two maxima corresponding to the two radiation zones of trapped particles around the Earth are clearly seen.

separated in space from the Sun. Now it seems that we must abandon even this degree of isolation. The physical conditions in the corona are now fairly well established out to a few solar radii. For example, at a height of half a solar radius above the visible disc there are about 3×10^7 atoms/c.c. and the effective temperature is a few million degrees. Recent calculations indicate that these conditions will result in an outward pressure which causes the material of the corona to expand outwards continually with a speed of between 500–1500 km./sec. This streaming material, which has been called the solar wind, envelops the Earth and the planets, and it seems that we live inside the shell of a disturbed field of solar plasma which extends to the outermost planets. The outer radiation belt surrounding the Earth must represent the interfacial region where the magnetic field and material of this solar wind has to reach a compromise with the Earth's own geophysical environment. These are new concepts which, with the radiation belts, amount to a revolution in our thinking about the controlling forces in the solar system. The concept of the solar wind should soon be put to a direct experimental test by instruments which are to be carried in an American deep space probe launched inwards from the orbit of the Earth towards the Sun.

This outpouring of radiation and particles from the Sun is the least tangible of the contents of the interplanetary medium. The shooting stars, or meteors, which are a feature of a clear dark sky, represent the burn-up in the Earth's atmosphere of particles which populate the interplanetary space. The relative infrequency of these as seen by a single observer on Earth gives a false impression of their numbers. The number of meteors entering the Earth's atmosphere which are big enough to produce a trail bright enough to be seen in a small telescope is about 8000 million per day. These are very small grains of dust weighing only about a ten thousandth of a gram. As the particles get bigger their numbers decrease. Objects which we recognize as



Moment of launching of a Pioneer space-probe from Cape Canaveral.

U.S. Air Force

bright fireballs probably weight about a gram, and there may be a million entering the atmosphere per day. Altogether about 1000 kg. of meteoric material burn up in the atmosphere every day, and another 500 kg. enters in such big pieces that these do not burn up completely and fall through to the Earth as meteorites.

No one is certain how these great quantities of dust originate. Two classes are commonly defined. The shower meteors move in a great assemblage pursuing an orbit around the Sun often identical with that of a comet. Regularly every year the Earth intersects a dozen or so streams of debris in its journey around the Sun and for a few nights there is a greatly enhanced rate of meteoric activity. Although to the naked eye these are the most spectacular occurrences, the greatest number of meteors move in ungrouped orbits and are known as sporadic meteors. Some years ago it was held that these meteors were pursuing hyperbolic orbits around the Sun and must therefore be meteors from interstellar space. One of the first results of the application of the radio astronomical techniques to the study of these meteors was the proof that the sporadic meteors moved in short period orbits around the Sun and were confined to the solar system.

During the last decade the photographic and radio echo study of meteors has led to notable steps forward in our understanding of these meteoric phenomena, and in the use of the trails which are formed in the atmosphere for the study of the physical conditions in the region of 80 to 120 km. above the Earth's surface. None of these techniques can investigate the particles which are too small to burn up. These are the micrometeorites. When the radius of a particle is less than about a millimeter the ratio of its surface area to mass is so large that the energy of interaction when it begins to enter the atmosphere is radiated away and the flight of the particle is stopped before evaporation occurs. Eventually these pieces of dust fall to Earth and from a study of the deposits on the ocean bed it has been estimated that the Earth collects something like a million tons per annum in this way.

Here is an obvious challenge to the techniques of Earth satellites, and scarcely a Russian or American satellite or probe has been launched which has not contained some form of device to study these micrometeorites before their interaction with the atmosphere. In principle the experiment should be easy—for example, a sensitive microphone to record the impacts. In practice the experiment has proved difficult since in the simple impact methods it seems likely that the microphones have recorded disturbances other than those caused by the impact of the particles and the calibration is uncertain. The results available at present indicate that both the U.S.S.R. and U.S.A. satellites and probes have recorded the impact of dust particles which weigh only 10^{-8}–10^{-9} g. and that the equivalent rate of impact over a surface of 1 sq. metre area is one every 1000 sec. (for 10^{-8} g. particles) and one every 100 sec. (for 10^{-9} g. particles). The Russian results tend to be lower by about one order of magnitude in frequency of impact.

These results imply that the spatial density of dust of this size in interplanetary space is 1000 or 10,000 times greater than that of the dust which is big enough to burn up in the atmosphere as meteors. This conclusion is not unexpected from the trend of increase of quantity of dust with decreasing size exhibited in the results of the Earth-bound measurements on meteors. The refinement of these measurements in space probes and satellites, coupled with further development in the ground-based photographic and radio echo meteor work, will certainly lead to a much better understanding of the rôle of these particles in the formation and evolution of the solar system. At present it is believed that the large meteorites which fall to Earth have a different origin from the meteors. Are the micrometeorites an extension of the size range of meteors or are they, too, a separate class? Does all this debris represent samples of the primeval material left over from the formation of the solar system or is it the consequence of some subsequent planetary catastrophe?

The Moon and Planets

A good deal of purely astronomical data about the Moon and the planets can be found in the textbooks. The distances, masses, sizes and many other facts have been deduced from a study of the motion of the planets by

normal visual and telescopic observations. There are, of course, some important gaps—Venus, for example, is cloud-covered and has yielded little reliable information about its period of rotation. Also, the existing errors in the measurement of the fundamental unit of distance in astronomy—the solar parallax—means that we are uncertain of the distance of the nearer planets to about 10,000 miles. Rather a small uncertainty in terms of the distance of a near approach of a planet to Earth of about 30 million miles; but quite critical when plans are made to send a space probe to the vicinity of a planet. On the whole though the essentially astronomical data are reasonably complete.

The astrophysical data are far less complete. The constitution of the planetary atmospheres has been inferred from spectroscopic observations but cannot be regarded as conclusive, and the density of the lunar atmosphere is below the limit of detection of any Earth-bound measurement. Nothing is known about the degree of ionization of these atmospheres. The geophysical information about the planets is very fragmentary. The surface of Venus has never been seen, and we do not know whether it is a complete ocean or an arid desert. The largest optical telescope is still inadequate to provide decisive information about the surface of Mars, and the evidence about the lunar surface (of which we had only seen one-half until the flight of Lunik III) is insufficient to settle the argument whether its surface features have been determined by volcanic activity or meteoritic impact.

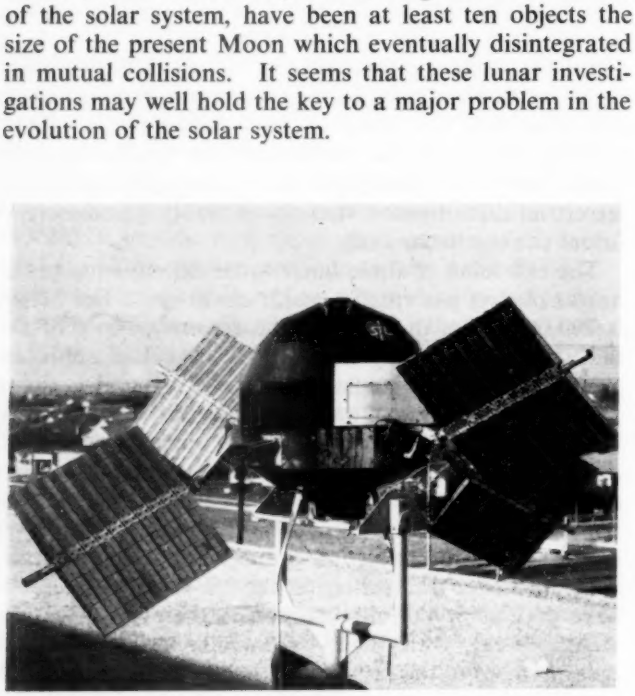
The more detailed study of the Moon and the planets has for some time appeared as a vital task for all who are interested in the problem of the origin of the solar system, and in the possible existence of organic material elsewhere than on Earth. The impasse which the conventional techniques had encountered has now been broken by the tools of radio astronomy and the space probe.

Radio telescopes have now measured the radio emissions from several of the planets in the region of centimetre wavelengths. This is the so-called thermal emission appropriate to the temperature of the body and useful comparison with the temperatures derived by optical studies are being made. More surprising is the detection of large sporadic outbursts on long wavelengths from Jupiter. The energies involved in the generation of these radio waves must be enormous. There is some evidence that the events occur on the surface of the planet rather than in its atmosphere. Should this be the case the forces at work must be equivalent to the energies involved in several hydrogen bombs, or in giant volcanic eruptions like the explosion of Krakatau.

These passive radio astronomical studies are full of interest but the greatest dividends are coming from the use of the radar or radio echo techniques of radio astronomy when applied to the Moon and the planets. After the war the further development of radar to achieve sufficient power and sensitivity in order to send a pulse of radio waves to the Moon and detect them again on Earth after reflection from the lunar surface was soon accomplished. Some people thought this was little more than a stunt, or at most a stage in the technical development of radars. However, those who pursued the problem have been rewarded by a most striking series of results. As soon as large steerable radio telescopes became available the study of the lunar radio echoes was much easier. It was found that although the pulses sent out from Earth remained always the same strength, those that returned $2\frac{1}{2}$ sec. later exhibited marked fluctuations in intensity. These fluctuations have been found to be caused by two different effects. First, in traversing the ionized regions surrounding the Earth the plane of polarization of the radio waves is rotated. This effect has now been turned into an important new technique for measuring the total number of electrons along the line of sight between the Earth and Moon. Second, the libration, or movement of the lunar surface relative to the Earth, causes a rapid fading in the reflected signals. The analysis of this fading revealed an unsuspected feature of the lunar reflection. It was assumed that the whole hemisphere of the Moon presented to Earth would take part equally in the scattering of the radio waves. This is not the case. The bulk of the scattering takes place at a portion of the forward hemispheric cap which is only about one-fifth of the depth of the lunar radius. This had an immediate practical reaction because it was realized that if the Moon behaved in this way as a reflector on radio wavelengths, then it should be possible to use it as a passive relation station for the transmission of intelligible speech over long distances. The excellent clarity of speech transmitted across the Atlantic in this way has been demonstrated, and since this is a form of long distance radio communication, which can be carried out on wavelengths which are not susceptible to ionospheric or other terrestrial disturbances, there is probably a commercial future in these techniques.

The extension of these lunar radar experiments to the nearer planets presented a major challenge. The Moon is 240,000 miles distant and the return journey of the radio waves from Earth takes $2\frac{1}{2}$ sec. At close approach Venus is nearly 30 million miles and the radar signal would take over 5 min. on the journey there and back to Earth. In terms of sensitivity of apparatus it is 10 million times more difficult to achieve than the lunar echo. However, a beginning has been made. An American team with a transmitter of a very great power on an 80 ft. radio telescope, and a team at Jodrell Bank using a smaller transmitter on the 250 ft. radio telescope have both achieved initial success in these Venus experiments. Even with these preliminary results a direct measurement of the distance of the planet has been made and the range of uncertainty about the value of the solar parallax has been significantly reduced. It is hoped that in the near future further extension of this work will enable the rate of rotation of the planet to be measured. It is likely, too, that the experiments will give some guidance on the nature of the surface of the planet.

At the moment no one can be sure whether the first determination of the rotation period of Venus will come from these radio astronomical studies, or from instruments carried in a space probe which either orbits or makes a close approach to the planet. There are, however, many aspects of these lunar and planetary studies which can only be achieved by the physical presence of instruments carried in space probes. Lunik II crashed its instruments on to the lunar surface. Soon we may expect control to be exercised in the final stages of flight. Then either a soft landing can be made and the instruments maintained in working order on the lunar surface, or the probe can be placed in close orbit around the Moon. Then we shall have the potential of studying the lunar atmosphere, and magnetic field (if any exists); and of making the detailed measurements on the lunar surface which may well have a decisive influence on many outstanding conflicts of opinion. The history of many aeons of time is contained on the lunar surface which must be almost untouched by erosion. Is there, for example, an identity of material between the meteorites which crash to Earth and the surface of the Moon? The analysis of certain meteorites made by Urey seems to indicate that at some stage in their history they must have gone through processes of heating which could only occur in the interior of a body of lunar size; and that these meteorites which we handle today are the result of a shattering of these Moons in collision. If this is correct there must, at some stage in the evolution of the solar system, have been at least ten objects the size of the present Moon which eventually disintegrated in mutual collisions. It seems that these lunar investigations may well hold the key to a major problem in the evolution of the solar system.



Explorer VI, successfully launched in August 1959 into an elliptical orbit around the Earth with an apogee of nearly 30,000 miles. The "paddles" contain solar cells for recharging the probe's chemical batteries. A similar payload was launched in March 1960 as Pioneer V and is now in a vast orbit around the Sun between Earth and Venus.

U.S. Air Force

The Search for Extra-terrestrial Life

Discussions of the possible existence of intelligent life on other planets in the solar system has for long been the domain of speculative writers. Little serious attention has been given to this by scientists, first because there seemed no reasonable prospect of carrying out any decisive investigations and second because the ideas about the mode of formation of the solar system led to a belief that it might be a unique process. The situation has changed with dramatic suddenness. To begin with, the idea that the Earth and planets were torn from the Sun by a passing star in an encounter which must be an extremely rare event in the Universe has been abandoned. Now we believe that the Earth and planets were formed by the accretion of large numbers of small solid particles from a dust cloud which was either formed with the Sun or which the Sun collected at some stage in its journey through interstellar space. This process must be a common occurrence in the Universe. Moreover, on the old view the existence of even the most primitive forms of organic material would have been impossible until a rather late stage in the evolution of the solar system when the outer layers of the Earth had cooled. On the accretion theory there is no reason why the pre-life processes should not have existed on the primeval dust and been preserved during the accretion phase. The question of the existence of organic material, and indeed of living organisms, in other parts of the solar system and the Universe is therefore removed from the astronomical to the biological domain.

The planets Mars and Venus are crucial in respect of any biological investigation. Their physical conditions and environment would not seem to be necessarily prejudicial to some forms of biological development, and indeed the presence of plant life on Mars is strongly suspected from recent spectroscopic studies. Instrumented probes will soon approach these planets—indeed the American probe intended to be placed in orbit around Venus was postponed in June, 1959, because of time scale difficulties only and not because of lack of capability. There are at least two crucial biological experiments now under development which will be carried in these future probes. One is an infra-red spectrometer, sensitive in the region of a few microns. If this instrument can be placed even within a few tens of thousands of miles of the planets it will be able to investigate the spectral regions where molecules of biological origin have very definite characteristics. The other is a microscope with an automatic collecting device which will feed it with samples of the planetary atmosphere (or surface, when a soft landing can be made). It will, of course, be associated with a device for transmitting the information back to Earth, but this should not be a major difficulty—the instruments in Lunik III have already accomplished a somewhat similar task in the transmission of the lunar photographs.

Unexpected encouragement to proceed with these ventures has come during the last few months from

remarkable analysis of the organic material of a meteorite made by Calvin and Vaughn of California. By a refined spectra analysis they conclude that molecules are present similar to cytosine, one of the bases which is part of the structure of nucleic acid. This seems to be a rather definite indication of the existence of prebiotic material on a body from outer space.

It is sometimes difficult to comprehend the excitement and gravity of the excursion of deep space probes to the nearer planets which will soon be launched by the American and Russian scientists. No human being can fail to be elevated by the thought that we are privileged to live in this age which has achieved the potential to investigate the existence of extraterrestrial life. On the other hand this privilege carries with it a most grave responsibility. Unless the utmost care is exercised these space vehicles may well contaminate the planets and their atmospheres with macromolecules which have developed on Earth. The intentional or accidental excursion of a probe into the environment of Mars or Venus before the biological instruments are ready might destroy for ever the validity of the biological investigations, and might, indeed, divert or destroy the evolutionary processes already at work in these domains. Two Great Powers are on the verge of these experiments and it is the scientific and moral duty of all concerned to see that no aspects of chauvinism lead to this disaster.

The Cosmological Problem

Although there is occasionally talk of probes moving with velocities near that of light, it is difficult for a working astronomer to rouse much enthusiasm for such futuristic devices as a useful astronomical tool in the foreseeable future. Even if such velocities could be achieved the dimensions of the present observable Universe are so great the the probe would travel for 100,000 years before leaving even our Milky Way system of stars. Any reasonable assessment of present circumstances leads to the conclusion that we must be satisfied with the developments of our optical and radio telescopes for the future exploration of the stars and galaxies which comprise the Universe—although indeed the future ability to erect such instruments on satellites outside the atmosphere or even on the Moon will certainly represent an important advance. Furthermore, this conservative view need cause no dismay, because the advance of radio astronomical telescopes during the last decade has engendered an optimistic outlook for the future investigations from Earth of the remote depths of space.

The investigations with the large optical telescopes during the last few decades have revealed the immensity of the problem facing the cosmologist. To begin with, any egocentric view which human beings might have about their place in the cosmos has been finally dispelled. The Sun and the solar system is in one of the spiral arms of a galaxy containing 10,000 million stars. The hub of this system, which is commonly known as the Milky Way, is 30 light years distant from the Sun, and the entire system extends for 100,000 light years in space. Many of the diffuse nebulae which Herschel thought might be external to this system have proved to be so. The nearest of these great extragalactic star systems is the famous spiral nebula M31, in Andromeda, similar in size and content of stars to the Milky Way but lying at a distance of 2 million years from us. Beyond, the telescopes reveal a Universe throughout which billions of these galaxies of stars are scattered out to the greatest distance of penetration yet achieved by the optical telescopes, 2000 million light years. The telescopes view these distant galaxies not as they exist now, but as they were when the light started on its jouney through space 2000 million years ago.

These galaxies exist in great groups or clusters, and as far as we can see the overall large-scale structure of the Universe exhibits a high degree of uniformity. Within the clusters the galaxies are in motion under their mutual gravitational attraction—for example, the Milky Way system and the Andromeda nebula, which are the chief members of the local cluster, are moving towards one another at a speed of 120 km./sec. On the other hand, the clusters as a whole exhibit a recessional movement—the expansion of the Universe. The speed of recession increases linearly with distance out to the present observational limit of 2000 million light years where it amounts to 60,000 km./sec. or one-fifth of the velocity of light.

If we retrace the past history of the Universe, then as we recede into history we might expect to find that all the clusters of galaxies and the entire material of the Universe would contract into smaller and smaller regions until at a time of about 10,000 million years ago, the primeval material of the cosmos was concentrated into a very small volume. Does this, in fact, represent the moment of creation of the Universe, or are we wrong in our interpretation of the observations? Is there, for example, a continuous creation of material, the pressure of which causes the expansion of the Universe, but all the time new galaxies of stars are in formation to replace those that recede from our field of view?

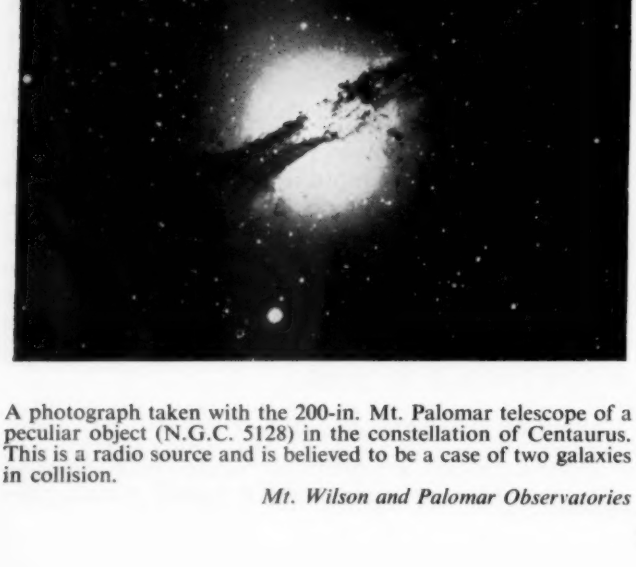
When the telescopes penetrate into space they look back into the past history of the Universe, we see M31 as it was 2 million years ago, the remote Hydra cluster as it was 2000 million years ago. Within this vast span of time and space there is little in the observational material to indicate either whether the uniform distribution extends to even more remote epochs, as it would do if the Universe was in a state of continuous creation, or whether the spatial density of the material of the Universe is increasing as it would do if the cosmos evolved from the superdense primeval material, 10,000 million years ago. A still further penetration is needed in order to explore those depths of space which may hold the decisive answer to this problem.

Radio Astronomical Studies of the Universe

During the last few years the results with the radio telescopes have encouraged us to believe that the new

techniques of radio astronomy may make a decisive contribution to this problem. The studies of the radio emission which come to us from outer space have revealed a complex situation. One of the simplest experiments in radio astronomy is to make a map of the strength of the radio waves coming from different parts of the sky. If this is done with a small aerial, or radio telescope, which receives in a broad beam, the results seem to indicate a general correlation between the strength of the signals and the density of common stars; that is, the strongest signals come from the regions near the brightest parts of the Milky Way which contain the most stars. Eventually, when large radio telescopes which receive the signals in a narrow beam are used to obtain a radio map of better definition, then new features begin to protude on this general correlation and now we know that the radio emission from space must have various origins. At the present time I think that there would be general agreement about the following summary of the position.

(*a*) The 10,000 million stars of the Milky Way are distributed in a large flattened disc across which light would take 100,000 years to travel. This system also emits radio waves over a wide range of wavelengths, but although there is a background emission, the strength of which follows closely the intensity of starlight, the common stars do not emit the radio waves. Apart from the Sun no one has yet succeeded in detecting radio waves from any of the common bright stars such as Sirius or Capella. It is likely that this emission comes from the ionized hydrogen gas which is concentrated in the plane of the Milky Way. The galaxy contains also, regions of neutral hydrogen gas, and it is from these that the spectral line on a wavelength of 21 cm. is emitted. The brilliant development of the investigations of this spectral line, particularly by the astronomers in Leiden, has displayed the detailed spiral structure of the Milky Way system in a manner which could not have been foreseen a decade ago. There are two further striking features of the radio emission from the Milky Way. First, there is a broadly distributed radio emission which extends far beyond the limits of the visible stars. This forms a galactic halo or corona and since there is no known material in these regions it seems possible that the emission arises from the movement of high energy electrons in the galactic magnetic field. Second, there are a relatively small number of discrete or localized radio sources (radio stars) concentrated amongst the stars in the Milky Way. The strongest radio source in the sky, in Cassiopeia, has been identified as a diffuse region of filamentary gas in violent motion. Another is coincident with the supernova of AD1054 (the Crab Nebula), and it seems quite possible that these Milky Way radio sources may all be the remains of supernovae in various stages of antiquity.



A photograph taken with the 200-in. Mt. Palomar telescope of a peculiar object (N.G.C. 5128) in the constellation of Centaurus. This is a radio source and is believed to be a case of two galaxies in collision.

Mt. Wilson and Palomar Observatories

(*b*) Outside the galaxy a few dozen of the nearer and brighter extragalactic nebulae have been identified with the radio telescopes. The Andromeda nebula is now relatively easy to study with contemporary instruments and it is apparent that this behaves as a radio emitter in the same way as our own Milky Way, including the presence of an extended corona outside the limits defined by the visible stars. It does not seem at the moment that any instruments are sensitive enought to detect more than this small number of normal, individual extragalactic nebulae.

(*c*) None of the sources mentioned in (*a*) or (*b*) can account for the most striking feature of any high sensitivity radio survey of the heavens, which shows several thousand localized radio sources which appear to have an isotropic distribution. We believe that these sources are extragalactic and that our failure to associate them with visible nebulae arises because they are peculiar objects at very great distances in the cosmos. The dozen or so which, after great labour, have been associated with faint objects photographed by the 200-in. optical telescope strengthens this belief. The most famous of these sources is in Cygnus—it is the second strongest radio source in the sky associated with a collision of two entire galaxies of stars at a distance of 700 million light years. Some other similar cases of interaction or collision are known in which objects which are almost invisible optically produce radio emissions which can be recorded quite easily with contemporary radio telescopes.

The modern radio astronomical techniques have given us new and powerful methods for investigating galactic structure and a wide range of astrophysical problems. Through the avenue of physical processes which are not yet understood it seems that radio telescopes may penetrate to regions of space beyond those attainable by the optical telescopes. The imagination is stimulated by the prospect that man now has the instruments at his

disposal on Earth to study events which are occurring at distances of several thousand million light years and which may give us the information about the condition of the Universe in those remote epochs which we believe may settle the conflict of opinion about the evolutionary processes of the Universe. Nature has never yielded her secrets easily and the attempt to settle this question is not proving an exception. The two main groups of radio astronomers in England, at Cambridge and Jodrell Bank, are engaged in this work. In terms of hard facts the radio telescope with which I am associated has already spent one-quarter of its 10,000 hr. of research time on the investigation of a single aspect of this problem. All that can be said now is that the results are encouraging, and there is nothing to undermine our belief that some, at any rate, of the unidentified sources may lie at distances of 6000 or 7000 million light years.

Conclusion

In this lecture I have chosen to speak about some aspects of the exploration of outer space because they interest me and because my daily life is wrapped up in some of the problems involved. Under these circumstances I know that it is easy to gain an exaggerated view of the importance and interest of the subject, and indeed to become too optimistic about the possibility of reaching solutions to problems which have faced man for all time. Even so, in spite of the hazards of the world today it does seem that we live in a privileged epoch in which man has achieved supremacy over great technical barriers so that we are enabled to explore two issues of tremendous importance to humanity, with bearings on the uniqueness of life and the origin of the Universe. Occasionally, people with a mundane view of existence ask why it is necessary to do such work. In this case one can only respond in kind, and point out that nearly all the technical devices on which the cultural and economic strength of the Great Powers is based can be traced back within a few decades to fundamental scientific research supported and carried out without expectation, or indeed, interest in, practical benefits. However, it is an innocent mind which does not see how the space probes, and the radio telescopes, have emerged from the cataclysm of war and that today they remain close relations of the defensive devices of nations. The danger, as I see it, is not that the aspects of research which I have discussed will lack support, but that they will be supported extravagantly for the wrong purpose. The devices of the scientist who is concerned with the exploration of outer space are double-edged. It would be an inconceivable disaster if they are built up and organized in such a way that they can too readily be switched in support of national jingoism at this crucial moment of the enquiry into the fundamental nature of life and the Universe.

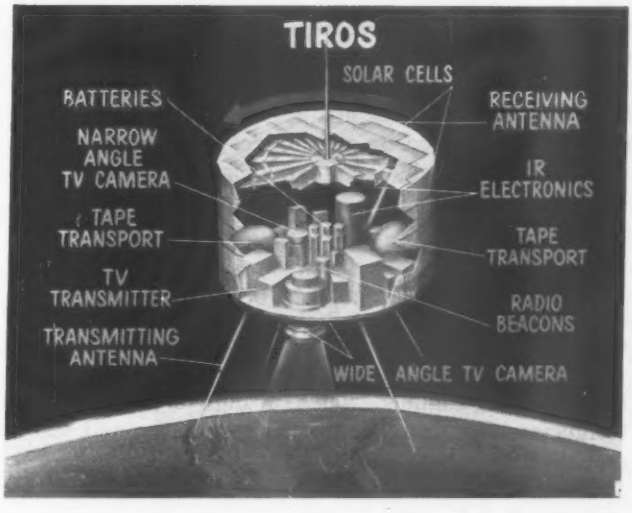
Spaceflight at the Planetarium

For the past two years, The London Planetarium has been fulfilling a most important function in introducing the public to the mysteries of astronomy. Now, in addition to this laudible task, they are preparing to conduct visitors on their first steps in astronautics.

The keen interest taken at the Planetarium in all matters of space-research is reflected by the many topical items which are included in their programmes. (A recent "scoop" was the inclusion of Transit I, the first navigational satellite, in a special navigational presentation only five hours after the launching).

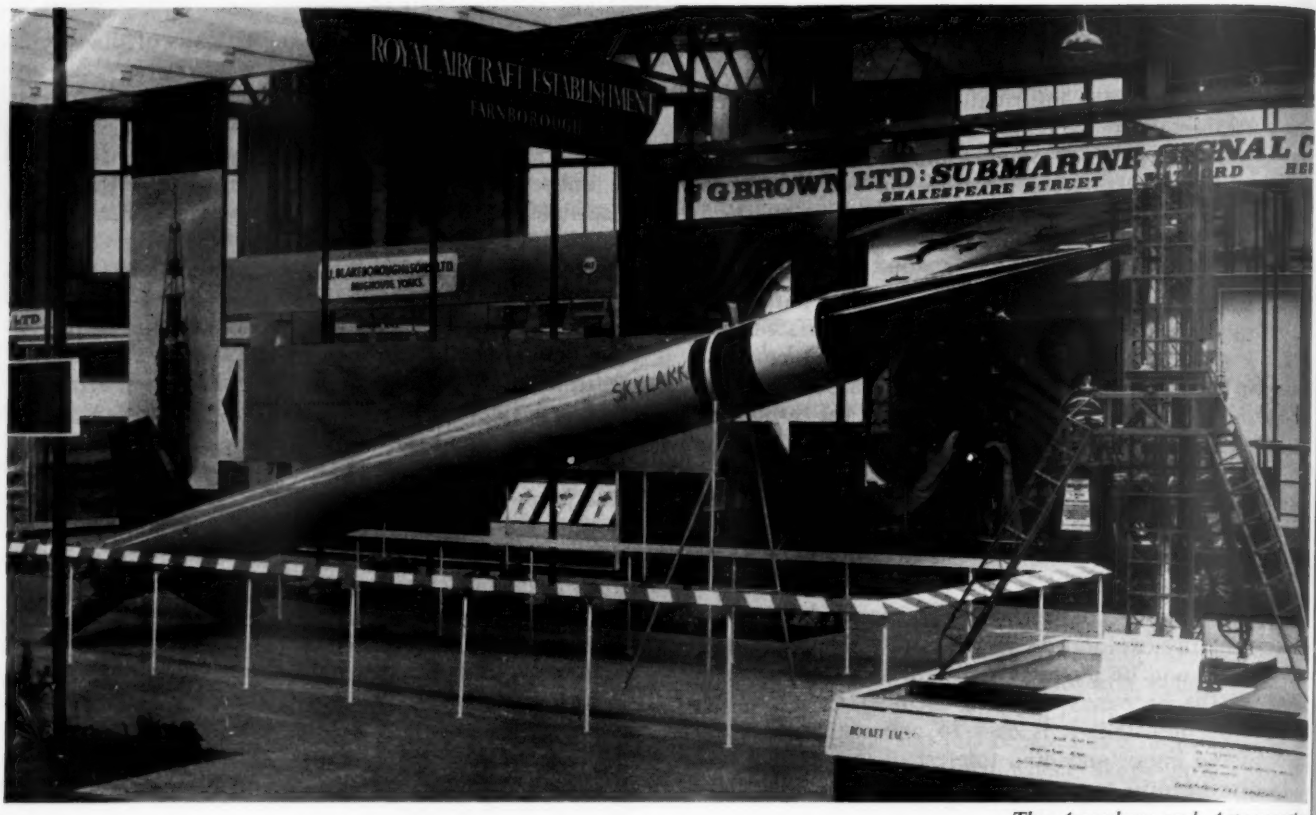
Now, for the first time, they are presenting a programme devoted entirely to space exploration. Visitors to the Planetarium at Whitsun and throughout the summer months will be given a vivid portrayal of contemporary progress in the space-sciences. Starting with Sputnik I and the "bleeps" which introduced the Space-Age, they will join Laika on her historic journey, reach still higher with Pioneer I and Van Allen, and rocket into space with the Luniks as they pass, hit and photograph the Moon. They will join Pioneer V as it travels into unchartered space and then, in graphic manner, stand with the scientists at Jodrell Bank as they establish contact with this latest ambassador, whose recorded voice will be heard sending back information from millions of miles in space.

Orbits shown in correct scale and perspective against the movements of the planets will bring many of the problems of space navigation and communications sharply into focus. As new satellites and space probes are launched, they too will be immediately incorporated into the programme.



Cut-a-way diagram of the Tiros II meteorological satellite. Tiros I, containing TV cameras but no infra-red detectors, was successfully launched on April 1 and has returned excellent pictures of large stretches of the Earth's cloud cover.

National Aeronautics and Space Administration



The Aeroplane and Astronautics

Skylark

A review of Britain's high altitude sounding programme

By MAURICE ALLWARD

Although Britain's efforts in scientific rocketry are small in comparison with those of Russia and America, they have produced exceedingly useful results. Indeed, they provide a model example of what can be achieved with moderate means by careful planning. Recently, interest in Skylark—our first upper air research rocket—has been heightened by an American proposal to use a number of these vehicles at Woomera.

Programme Initiated

The idea of Britain undertaking a programme of upper atmosphere research was first discussed at a meeting of the Gassiot Committee of the Royal Society in October, 1953. This followed a conference held at Oxford during the previous summer, when a number of American technicians had lectured on the techniques and results of U.S. rocket experiments.

Discussions were then held between the Committee and the R.A.E., which were followed by joint representations to the Treasury, as a result of which a financial grant was secured.

The R.A.E. undertook to develop rockets suitable for carrying out the desired experiments. The result was the Skylark—Britain's first high altitude rocket—designed to carry a payload of 100–150 lb. to altitudes between 70 and 90 miles. Basically it is a very simple vehicle, cylindrical in shape with a conical nose, 25 ft. long and 17·4 in. in diameter, with a launching weight of 2560 lb. It is aerodynamically-stabilised by three large fixed fins and is uncontrolled in flight. A Raven solid-propellent motor gives a thrust of about 12,000 lb. for about 30 sec.; the exact period being determined by the shape of the charge. This motor was larger than any previously made in this country, and was developed by R.P.E., Westcott. The Banwell Division of the Bristol Aircraft Co. (now Bristol Aerojet) manufactured the motor case.

The nose portion is made in two parts; a 65-in. long cone and a 30-in. parallel bay. The cone provides 2·7 cu. ft. of payload space and the bay a further 2·3 cu. ft. Both cone and bay can be pressurized independently.

The Skylarks are launched from Woomera, in South Australia, by agreement with the Australian Department of Supply and with the co-operation of the Woomera Rocket Range authorities. A special 81-ft. launching tower, supported on gimbals in a tripod base, was developed for launching purposes. The gimbals permit the tower to be adjusted between 15 degrees forward of the

vertical in elevation and 10 degrees either side, control being by remotely controlled electric motors. The rocket rides in three guide rails; shoes on the rocket engage in the rails and prevent rotation.

Both radio and optical instruments are used to track the vehicles and so obtain trajectory information.

Tracking and Communications

For optical tracking, the rocket is photographed in flight by high-speed cameras and by kine-theodolites, the former giving a record of vehicle behaviour during the launching phase. Several widely-spaced kine-theodolites are used, each of which photographs both the rocket and a set of elevation and azimuth dials, so that the rocket position can be calculated using triangulation methods.

Information obtained in the rocket is transmitted to the ground receiving stations by a telemetry sender. The standard transmitter uses an AM/FM system at 465 Mc/s. and is capable of giving 100 accurate readings per second for up to twenty-four instruments. Electrical power is provided by special lightweight batteries; these drive rotary convertors where necessary. The batteries take up valuable space and payload and, in accordance with conventional guided weapon practice, are kept to a minimum by running all instruments on ground supplies until immediately prior to firing.

For the radio tracking, a micro-wave beacon is carried in the rocket and two ground receivers, widely separated, lock-on to the signal and provide a continuous record of the relative azimuths and elevations of the rocket. Computors then calculate the path of the rocket throughout its flight.

The radio Doppler system is also used to give velocity and position information. A ground transmitter sends a continuous wave signal to the rocket; a transponder in the rocket doubles the received signal and re-broadcasts it to the ground. A ground receiver compares this received frequency with the original transmission suitably doubled and obtains a Doppler beat frequency which is a measure of the radial velocity of the rocket with respect to the receiver. If three receiving stations are employed the rocket's velocity in space may be computed, and its position can be determined with accuracy after summing the Doppler beats along each radial line.

By combining the results of these three systems—using the results from one system to fill in gaps in the record of another—graphs of the rocket's trajectory, speed and acceleration can be plotted and from these, information can be obtained about the flight behaviour of the vehicle up to its maximum speed of five or six times the speed of sound.

If the rocket flight were an ideal one the measurements on the rocket behaviour would be complete, but in fact the rocket does more than describe a trajectory. It rolls, pitches and yaws for a variety of reasons: rolling arises from slight imperfections in the structure, pitching and yawing may be set up by the varying winds encountered, and these motions may develop and become quite large as the rocket leaves the effective atmosphere, actually causing it to tumble.

To follow these additional motions both in the atmosphere and above its effective limit, gyroscopes and accelerometers are carried inside the rocket; these instruments measure the changes in orientation and the forces causing them, passing the measurements in the form of changes of voltage or inductance to the telemetry sender in the rocket which transmits the information to the ground. There the results are extracted, displayed and photographed for careful analysis in the laboratory. In these, and other ways, the vagaries of the rocket flight are followed in detail although the rocket may be many miles away, invisible and travelling at several thousands of miles per hour.

Research Planning

In planning the research programme, it was realized from the beginning that there was little value in repeating work already in progress elsewhere. The choice of experiments was therefore based on the following considerations:

(1) The advantageous situation of the Woomera Rocket Range as regards geographic and geomagnet latitude. (The importance of wide latitude coverage has been amply demonstrated by satellite observations on the gross physical parameters of the atmosphere and on comparisons of data obtained at Fort Churchill and White Sands).

(2) The importance of studying diurnal and seasonal and secular behaviour of the upper atmosphere and the Sun.

(3) The need for a systematic study of regions of the atmosphere which were already being neglected for the glamour of greater heights, or which presented problems of special difficulty.

(4) The need for confirmation of some existing data by fresh techniques capable of greater precision and less affected by disturbing factors.

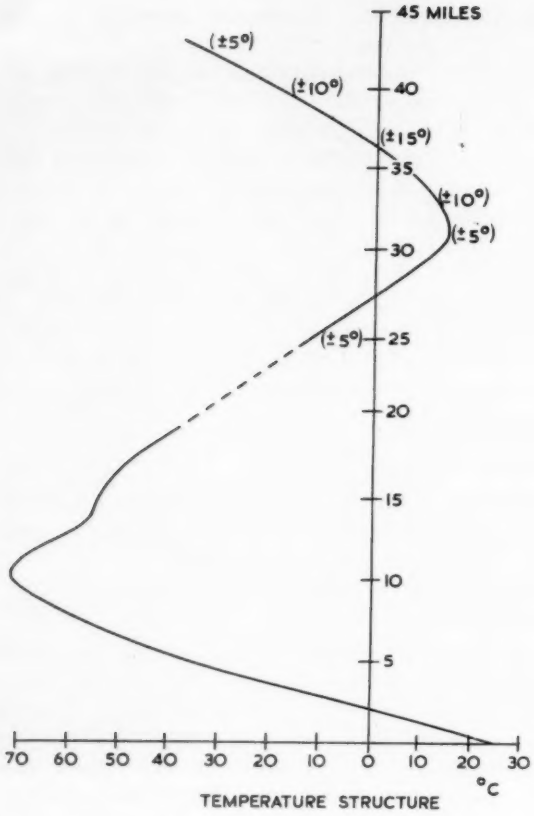
(5) The need for co-ordinated observations at the same time on related phenomena, for example solar and ionospheric behaviour.

To implement the chosen programme, the aid of five university groups was enlisted; these started work on experiments of their own choice in April, 1955. The universities concerned are: Queen's University, Belfast; Birmingham University; Imperial College, London; University College, London; and the University College of Wales. The Royal Observatory, Edinburgh, has also made proposals which are being actively considered.

Table I gives a list of the planned experiments. On average, two main and one or two subsidiary experiments are carried out on each launching.

Measurement Techniques

It is possible to measure wind temperature and density by means of pressure gauges on a rocket, and indeed



Temperature structure of the atmosphere obtained with Skylark No. 4 on November 13, 1957, at Woomera.

over a limited height range it is well worth carrying gauges for this purpose. For this reason whenever possible R.A.E. fits pressure gauges in various locations on the rounds. Greater precision, however, may be attained by measuring the velocity of sound. The study of the upper atmosphere by observing the sound from explosions has been caried out sporadically since the beginning of the century; for instance by the U.S. Army Signal School in observing the time and angle of arrival of sound waves from grenades fired in the upper atmosphere.

A new approach has been adopted by University College, London. A widespread array of microphones is set up covering a circle of 20 miles in diameter. By successive approximation the temperature and wind field, giving the observed times of arrival of the sounds from eighteen Skylark carried grenades, is calculated. For this work special ballistic cameras of high precision have been built at University College, and a high speed shutter system enables locating photographs of the grenade bursts to be obtained even during daytime.

The Skylark was Britain's first venture into the realm of high altitude sounding rockets, and six rounds were reserved for proving trials and to enable missile "know-how" to be obtained before the actual research programme began.

The first round was fired on 14 February, 1957. In this, no attempt was made to achieve maximum height. In fact, the launching cradle was depressed as far as possible and the rocket flew a long, flat trajectory. Rounds 2 and 3 were also proving firings. These three launchings proved the general performance of the vehicle and its motor, and attention was then turned to trials of equipment and instrumentation and the associated ground equipment. Skylark No. 4, in addition to routine instrumentation, carried equipment for four separate experiments involving grenades, metal foil "window," a dielectric experiment and pressure gauges. Fired on 13 November, 1957, it reached a peak altitude of 83 miles.

Skylark No. 7 (launching No. 6), fired on 17 April, 1958, to an altitude of 90 miles, was the first British contribution to the International Geophysical Year of 1957–58. The rocket carried eighteen grenades and fourteen cartridges of "window," and incorporated an insulated cone for ionospheric experiments.

The grenades were timed to explode at intervals between 100,000 ft. and 330,000 ft., as part of an experiment designed to measure temperatures and winds, using the method developed by University College, London. The "window" was timed for release as two separate "clouds" at 140,000 ft. and 234,000 ft.; these were then tracked by radar to give the Department of Meteorology, Imperial College, information on high-level winds.

Sixteen of the eighteen grenades functioned, and a most interesting phenomenon was observed with the explosion of the highest. This produced a white luminous cloud, which expanded to a diameter of about $1\frac{1}{2}$ miles and remained conspicuous for 4 min. No other grenade produced this effect, the next two highest being a GW-1 type at 60 miles and a GW-2 at 57 miles.

At the time of the experiment, sunlight could only reach heights above 600 miles, so this was not the cause of the emission. The exact cause of the phenomenon remains a mystery, although it is believed to be due to a reaction between atomic oxygen and one of the products of combustion.

The cloud was, of course, completely unexpected but, owing to prompt action by operators manning the S.T.S. (Satellite Tracking Station), Woomera, a Baker-Nunn camera, trained on the grenade flashes, secured a sequence of exposures, each exposure being on a separate frame. Thus a complete photographic record is available which will provide useful basic data for determining the exposure sequence for the tracking of luminous clouds in any future grenade experiments.

Rocket Week, 1958

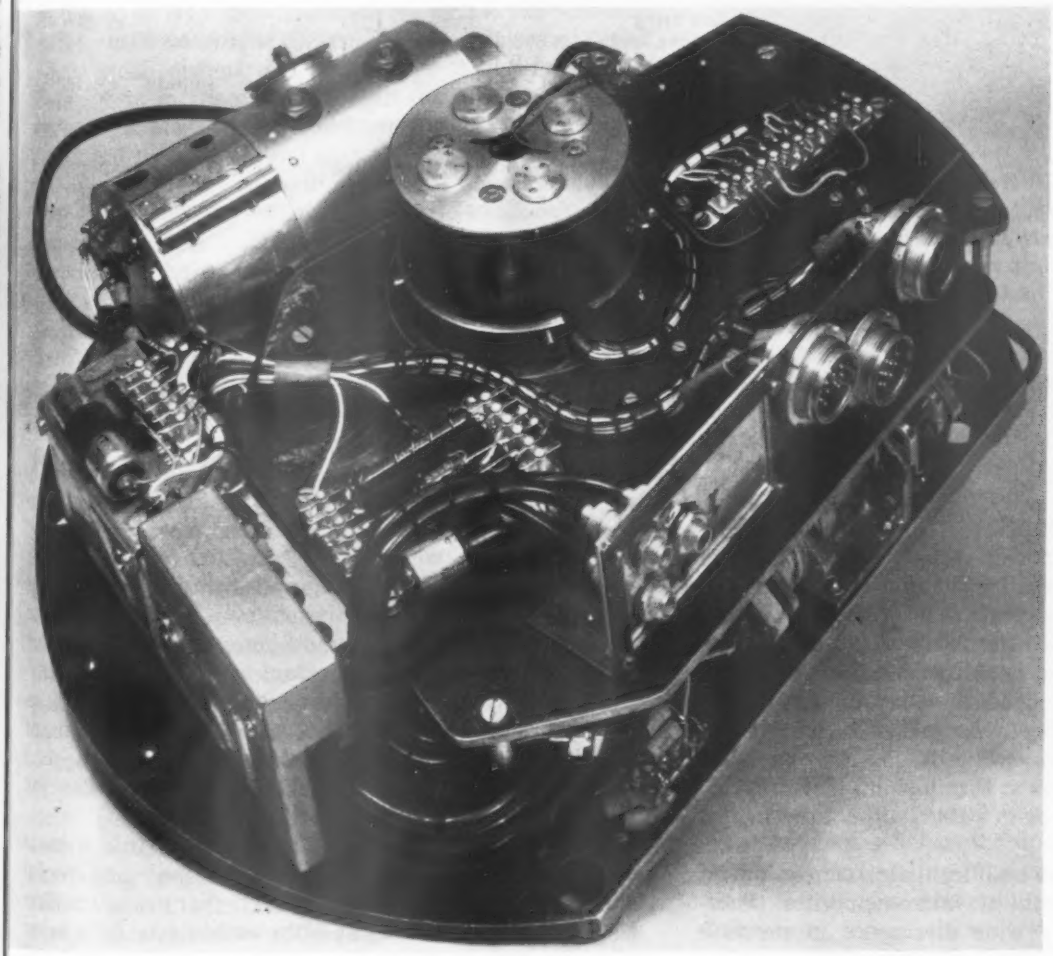
Following the recommendation of the Washington Rocket and Satellite Conference to establish a special "Rocket Week" during June, 1958, two Skylarks were launched on the target dates of 18–19 June. The first of these, Skylark No. 18, suffered motor failure—the

TABLE I—*Skylark Research Programme*

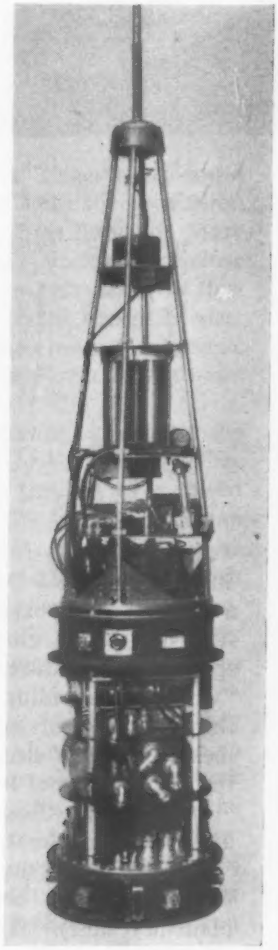
Study of Wind, Temperature and Density		
*	Grenade experiment	University College, London
*	Radar-reflecting material experiment	Imperial College, Meteorology Department
***	Falling sphere experiment	University College, London
*	Sodium cloud (temperatures)	Queen's University, Belfast
*	Sodium cloud (winds)	Queen's University, Belfast, and University College, London
*	Pressure gauges	R.A.E.
Study of Ionosphere		
*	Ionosphere dielectric experiment	Birmingham University
**	Ion cage	Birmingham University
**	Langmuir probes	University College, London
***	Radio Doppler	University College of Wales and R.A.E.
***	Radio pulse	University College of Wales and R.A.E.
**	Sporadic-E probe	University College, London
***	Mass-spectrometer probe	University College, London
Radiation Experiments		
**	Photometry of "green line"	Queen's University, Belfast
***	Photometry of OH bands	Queen's University, Belfast
**	Ionization chamber solar Lyman—a	University College, London
***	X-ray counters	University College, London
**	X-ray emulsion detectors	University College, London
Other Experiments		
**	Micrometeor microphones	Queen's University, Belfast
***	Proton precession magnetometers	Imperial College, Geophysics Department

KEY:

* experiments already fired once or more
** experiments awaiting firing or fully developed
*** experiments still under development



Skylark instrumentation.



A typical Skylark payload.

Crown copyright reserved *Crown copyright reserved*
Reproduced by permission of the Controller, H.M. Stationery Offic

only such failure out of a total of eleven firings. The second launching, arranged within 24 hr. of the first, achieved the desired results.

Another notable success on the rocket handling side was the firing, on 3 December, 1958, of Skylark No. 11 for a special experiment. This required the rocket to be fired with the Sun at a depression of 6°, and the launching was achieved within 2 min. of the optimum time.

Seven more rounds, completing the first series of firings, are either ready for firing or in advanced state of preparation. Another twelve rounds are in the final planning stage.

A second "Rocket Week" was planned between 16 and 22 November, involving the simultaneous launching of rockets with associated experiments in different parts of the world. Bad weather, unfortunately delayed the British firings, but the three Skylarks earmarked for this work were successfully fired during a 36-hr. period over 30 November to 1 December. The first of these carried a sodium vapour experiment initiated by Queen's University; the second employed grenades to measure atmospheric temperatures and vertical wind speed, with "window" providing independent values of wind. The third Skylark carried three experiments, one being the measurement of electron densities in the ionosphere by the Department of Physics at Birmingham University.

In addition to those listed in Table I, other experiments are under consideration:

Queen's University have built transistorized equipment for microphonic detection of micrometeorites (interplanetary dust). A very wide divergence in previous results makes an independent attack on this problem most desirable.

Work on a proton precession magnetometer is progressing at Imperial College. So far data on the location of upper atmospheric currents have been limited to the equatorial and polar regions.

One of the most surprising of recent results of upper atmospheric research has been the realization of the rôle of the oxides of nitrogen in ionospheric equilibria. Recently laboratory work has been instituted at Universith College to investigate some of the basic reactions that occur between nitrogen and oxygen in their molecular, atomic or ionized states. It is hoped that this work may also lead to a study of the composition of the atmosphere at great heights by the method of releasing selected chemical substances. The study of the grenade glow, mentioned previously, is a start in this direction.

In addition, the R.A.E. is undertaking a number of experiments, including a project for a "sun-seeker." This is a device which homes or fixes on the Sun to enable long exposure spectrographs to be made in flight. The Sun plays a dominating rôle in determining the character of the upper atmosphere, and a sun-seeker facility will open up an important avenue of research.

One might add, in conclusion, that efforts are now in hand to raise the performance of Skylark by means of a high-thrust booster (total impulse 81,000- lb./sec.) operating for about 4 sec. This should increase the rocket's maximum altitude to 120–130 miles.

From the foregoing it will be evident that a most enterprising programme is well under way and useful results being obtained using a comparatively modest rocket. Most encouraging is the enthusiastic help being given by Universities. The experience gained will be of great value when the time comes for Britain to launch her own Earth satellites.

TABLE II—*Skylark—List of firings*

Launching No.	Date	Skylark No.	Altitude (miles)	Remarks
1	14.2.57	1	7	First proving firing; no observation made. Flat trajectory launch
2	22.5.57	2	47	Test firing
3	23.7.57	3	53	Test firing
4	13.11.57	4	77	Proving firing, but extensive instrumentation and grenades fitted
5	2.4.58	6	—	Propulsion test (R.A.E.)
6	17.4.58	7	91	First I.G.Y. and Gassiot firing. Grenades and "window" ejected at intervals
7	20.5.58	5	94	Test firing; incorporated airglow measurement experiment. Nose cone jettisoned
8	18.6.58	18	—	Special I.G.Y. night firing. Motor failed—only motor failure experienced to date
9	19.6.58	9	90	Special I.G.Y. night firing; successful dielectric experiment of electron density
10	19.9.58	8	97	Fourth Gassiot firing. Telemetry failed
11	3.12.58	11	79	Fifth Gassiot firing. Carried sodium experiment
12	6.4.59	10	—	Failure
13	8.7.59	14	58	Carried ion probe and X-ray film
14	19.8.59	17	90	Carried ion probe
15	17.9.59	12	83	Ion-cage ejected during return fall
16	24.9.59	15	100	Repeat of above
17	30.11.59	16	97	Sodium vapour experiment. Vapour ejected above 40 miles to obtain data on atmospheric temperature and winds
18	30.11.59	60	105	Ejected grenades and "window"
19	1.12.59	38	100	Ejected grenades and "window." Also dielectric measurement of electron density in the ionosphere.

Exploration of the Moon—1

The Lunar Objective*

By PATRICK MOORE, F.R.A.S., F.R.S.A.

The space age has well and truly begun. Instrumented probes have been sent far beyond the Earth, and the idea of a manned lunar voyage is universally admitted to be rational. Matters have developed to a degree which even the pioneer members of the British Interplanetary Society could hardly have expected when they first gathered together in the early 1930's to lay their plans and face up to what amounted to general ridicule.

So far as we are concerned, three worlds may be regarded as accessible: the Moon, Mars and Venus. Mars has points of resemblance to the Earth, and the recent discovery of water-vapour in the atmosphere of Venus gives a new light to that peculiarly baffling planet, but there can be no doubt that the Moon is our first target—not because it is in any way friendly, but simply because it is so much closer than any other natural body in the sky. Its mean distance from us is a mere 239,000 miles, while Venus is always 100 times as remote, and Mars more distant still. Moreover the Moon is our companion in space, and for this reason alone is much easier to contact. As we all know, vehicles have already been sent to it and round it.

Any small telescope will show considerable detail on the lunar surface. There are broad darkish plains, known as "seas"; there are vast numbers of walled formations termed craters; there are mountain ranges, isolated peaks, cracks or "clefts", and various minor features such as domes. A few nights' study, with the help of an outline map, will enable the beginner to "get his bearings" and to learn how to recognize the main features of the lunar landscape.

When observing the Moon, there are several points to be borne in mind. Full moon is the worst possible time to start trying to identify mountains and craters; at this time there are no appreciable shadows, and the scene is dominated by the mysterious bright rays emanating from a few formations such as Copernicus, Tycho and Kepler. More spectacular views are obtained during the crescent, half and gibbous phases, when craters near the terminator (the boundary line between the daylight and night hemispheres) appear partly filled with shadow, and stand out magnificently.

The "seas" or *maria* are by no means as smooth as they look, and contain craters of all sizes, as well as clefts, peaks and other features. It is noticeable that most of them are essentially circular, though foreshortening naturally makes them appear elliptical. (The Mare Crisium, for instance, is actually slightly elongated in an east-west direction, though foreshortening creates the impression that it has a longer north-south diameter.) There seems no escape from the conclusion that the well-formed *maria*, such as Mar Imbrium, Mare Serenitatis, Mare Crisium and Mare Nectaris, are close relations of the craters; indeed, there is no obvious difference between such a *mare* and a crater, except in size. Grimaldi, a large, dark-floored crater near the Moon's eastern limb, might indeed have been ranked as a *mare* had it been better placed on the lunar disk.

The craters are everywhere. They are found on the *maria*; they cluster thickly in the bright uplands, they interrupt and ruin each other, and they are even found on the tops of peaks and domes. The largest lunar map yet drawn—the work of the late H. P. Wilkins, who served for some time on the Council of the British Interplanetary Society—shows well over 50,000 of them, ranging in size from the immense Bailly, with its diameter of almost 180 miles, down to tiny pits at the very limit of visibility.

Many of the craters are extremely deep, and yet they do not have the form of steep-sided wells. Drawn in profile, they are seen to be much more similar to shallow saucers. The outer wall is not usually high above the exterior plain, whereas the floor is considerably sunken. An explorer standing in a crater such as Plato would have no feeling of being shut-in; with some of the large formations, indeed, the walls would be below the horizon of an observer standing near the centre. Remember, too, that on the Moon the horizon is considerably closer than on Earth.

* *First part of a three-part symposium on The Exploration of the Moon, given before the British Interplanetary Society on 5 March, 1960, at Caxton Hall, London.*

The problem of the origin of the craters is of some interest to astronauts as well as astronomers, since it is linked with studies of the nature of the lunar surface. According to one theory, the craters are due to impacts of meteoric bodies from space; an alternative explanation is that they are basically volcanic—though "igneous" would be a better term, since the large formations are not at all like terrestrial volcanoes of the Vesuvius or Etna type. This is not the place to discuss the strengths and weaknesses of the rival hypotheses; the present writer is prejudiced in favour of an igneous theory, since the distribution of the craters is not random, and various characteristics of the craters are difficult to explain by impact—but as yet there is no general agreement. (It is true, however, that there are many features on the Moon which look remarkably similar to true volcanoes; these take the form of founded elevations with summit pits. They used to be regarded as rare, but during the past few years I have listed nearly 100 of them, and they seem in fact to be relatively common.)

Changes on the Moon are still a matter for discussion. The classic case is that of Linné, on the Mare Serenitatis. Up to 1843 it was described as a deep, conspicuous craterlet; since 1866 it has taken the form of a minute pit on an elevation, and surrounded by a whitish nimbus. "Obscurations" inside some of the craters have been recorded by many observers, including myself, and are difficult to explain away, though they are not easy to account for. However, the most interesting report of activity comes from Soviet Russia. In November, 1958, a definite outbreak inside the crater Alphonsus was anounced by N. Kozirev, working with the 50-inch reflector at the Crimean Astrophysical Observatory. Spectrograms were obtained, showing a high-temperature area with the emission of carbon gas, and these seem to show conclusively that the Moon is not quite so inert as many authorities had believed.

The nature of the surface is obviously of paramount importance. Virtually no colours are seen, and the general impression is that the Moon is wholly or partly covered with a layer of ash or dust—presumably volcanic and meteoric. T. Gold has suggested that the layer may be very deep, so that, in his words, "space-travellers of the future will simply sink into the dust with their gear." This view is not generally supported—for which would-be astronauts will be profoundly thankful!—and it is perhaps more likely that the layer is only an inch or two deep, though a certain amount of doubt must remain.

We do know that the surface materials are very poor conductors of heat. At mid-day on the lunar equator, the temperature rises to over +215° F., but at midnight sinks to about −250° F. We cannot evade the coldness of night, but we can avoid intense daytime heat simply by avoiding low latitudes. Nearer the lunar poles, the maximum temperature is much less, and this is one reason why the first manned vehicles will presumably land well away from the equator.

Another vital question concerns the presence or absence of a lunar atmosphere. Of course, there is no question of there being an atmosphere dense enough to breathe; but even a tenuous mantle would act as an efficient meteor-screen, and ten years ago it was thought that the ground density might be some 1/10,000 of that of the Earth's atmosphere at sea-level. This estimate, due to the Russian astronomer Y. N. Lipski, has not, however, been confirmed, and modern opinions give the maximum permissible value as much less—so slight, indeed, that as a protection against meteors the lunar atmosphere is likely to be useless. Here again doubts must remain, but it is wise to be prepared for the worst.

Life on the Moon must be regarded as most improbable. We may at once discount advanced organisms, to say nothing of the "insect swarms" seriously proposed by W. H. Pickering less than a quarter of a century ago; but lowly plant life is much more adaptable, and until recently it was thought possible that certain streaks inside craters of the Aristarchus type might be explained in this way. I certainly held this view—and am not ashamed of having done so; it was shared by many more competent observers. Yet modern research seems to show clearly that it is wrong, and that there are more plausible explanations of the dark features. The balance of evidence now available to us indicates that the Moon is lifeless, and will remain so until men from Earth land there.

One problem best tackled by the space-probe method is that of possible lunar magnetism, which is linked with the question of radiation zones round the Moon. The Earth, as we know, has a considerable magnetic field; so apparently has Venus, which is strikingly similar to our world in size and mass. The Moon is less dense than the Earth, and there have been suggestions that it lacks a terrestrial-type metallic core. In this case no appreciable magnetic field would be expected, and the results obtained from Luniks I and II bear this out. Encircling radiation belts of the Van Allen type seem also to be lacking. Neither will there be any radio-reflecting layers around the Moon, and this will limit surface communication to the distance of the horizon. An observer on the Moon will be unable to call up another lunar explorer by radio, once the horizon has been passed—unless, of course, he routes his message via the Earth. Nature can play some strange tricks on us.

The visible face of the Moon has been carefully mapped, but until 1959 there was almost complete ignorance as to the averted hemisphere. The Moon revolves on its axis in the same time that it takes to move once round the Earth (27⅓ days), and so presents the same face to us all the time—though the fact that the lunar orbit is elliptical, not circular, causes "wobblings" or librations, and from Earth we can examine a total of 59% of the entire surface. The only way to extend our knowledge was by space research, and this was accomplished in October, 1959, when the Russian vehicle Lunik III went round the Moon and sent back photographs of much of the hidden side.

Though amazingly good in view of the conditions under which they were obtained, the Lunik III pictures

are naturally lacking in definition, and delicate features do not show up. Wide areas of the "other side of the Moon" appear blank, and it has been suggested that the new regions are therefore smoother than the old. This opinion is quite unjustifiable, and future photographs will almost certainly show a similar profusion of peaks, craters, clefts and other features. The only real difference is that there are few *maria*—a fact anticipated long ago by various theoretical considerations.

The Russians have allotted names to the main formations on the far side of the Moon; we have the Moscow Sea (Mare Moscovianum), the Sovietsky Mountains, Tsiolkovskii, Lomonosov and others. Among the new names appears that of Jules Verne. Nobody is likely to begrudge the great French story-teller this honour; and it is much to be hoped that the Russian names will be accepted without question.

The Lunik III pictures add much to our knowledge; they prove what astronomers had always so strongly suspected—that the other side of the Moon is as barren and forbidding as the face which we have always known. Before long we may hope to have an adequate chart of the whole Moon instead of only 59% of it.

Intensive studies of the Moon are now being carried out not only by amateurs, but also by professional astronomers. This is a new departure, since the average professional has hitherto regarded our satellite as decidedly uninteresting and parochial; and it underlines the radical change of attitude which has taken place during the last decade.

It seems worth speculating a little as to what is likely to happen next. Lunik II was the first vehicle to hit the Moon, and other landings will certainly be made; these should yield more information as to the nature of the surface layer (though it is devoutly to be hoped that no nation will be so insane as to equip a space-probe with a nuclear explosive device). The next step should be a "soft landing", in which a probe will be brought down sufficiently gently to avoid the destruction of its instruments. The Moon is a splendid natural laboratory; its virtual lack of atmosphere means that it is exposed to radiations of all kinds, and an automatic lunar transmitting station would be invaluable to astronomers, physicists and others. Further "circum-lunar" probes will be built, some of which will enter closed orbits round the Moon, and all the time we come closer to the greatest experiment of all—the first lunar voyage. By the time it takes place, we will have found out more about the Moon, and will know whether it is likely to give us any help in the construction of a research base. So far, we have to admit that we have very little idea of what to expect.

This, then, is the Moon—a barren, hostile world indeed, but with a fascination all its own. It represents a challenge, and we may now be confident that this challenge is one which mankind will not ignore.

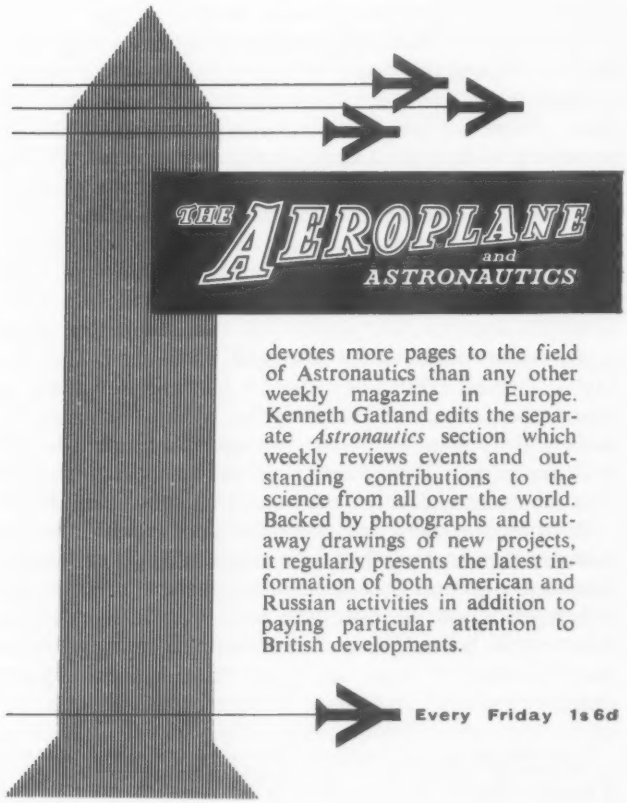
FOR THE BEST IN TRAVEL BY SEA, LAND AND AIR CONSULT

NTA

Northern Transport Agency (London) Ltd., 47/48, Duke St., London, S.W.1.

Telephone WHI. 4346

AIR TRAVEL
AIR FREIGHT
AIR CHARTERS
SHIPPING & RAIL ETC.


THE AEROPLANE and ASTRONAUTICS
devotes more pages to the field of Astronautics than any other weekly magazine in Europe. Kenneth Gatland edits the separate *Astronautics* section which weekly reviews events and outstanding contributions to the science from all over the world. Backed by photographs and cutaway drawings of new projects, it regularly presents the latest information of both American and Russian activities in addition to paying particular attention to British developments.
Every Friday 1s 6d

Exploration of the Moon—2

The Robot Explorers*

By KENNETH W. GATLAND, F.R.A.S.

On his own man would be a very imperfect instrument for the exploration of space. Since the earliest times his ability to make and use tools has not only enhanced his well-being and comfort but has enabled him vastly to enlarge his understanding of Nature.

How limited indeed would our knowledge of the Universe be if we had to rely on our own limited senses as probing instruments. Space is filled with all kinds of radiations whose nature would have remained forever unknown to us but for the ingenious instruments which man has devised to extend his knowledge.

We would know nothing of cosmic rays, solar X-rays, or radio emissions from the stars, or any one of a whole range of phenomena which exist beyond the narrow wave-band of the visible spectrum.

In company with the rapid development of scientific research instruments over the past decade we have entered the era of automation, and although we have yet to devise a machine which will relieve us of the task of thinking, we have electronic computers which can solve the most complex mathematical problems in a fraction of the time it would take a team of mathematicians.

In some of our factories we have machines which, fed with appropriate instructions on tape, will mass-produce complicated parts without human aid.

Today we are witnessing the beginnings of spaceflight, and it is logical that many of these techniques of instrumentation and automation should be applied to this new task. Indeed, since the space-age began with the launching of Sputnik I only 29 months ago, remarkable things have already been accomplished with artificial satellites and space-probes, which have returned to us knowledge of hitherto unsuspected phenomena which, cosmically speaking, exist on our own doorstep (*e.g.*, the Van Allen radiation belts).

Within the first few months of this new era of space exploration, we have an example in Sputnik III of a heavy "orbital laboratory" which has radiated tracking signals for almost 2 years using a radio transmitter energized by solar batteries. In such equipment as this is being proved the essential reliability that must enter into the design of future man-carrying space-vehicles.

In principle, there does not seem very much difference between the machine that runs unattended on the factory floor and one that is launched into space and, let us say, is landed on the Moon. The only real difference is its remoteness from human supervision and the obvious need to ensure it does not break down before its job is done.

* *Second part of a three-part symposium on "The Exploration of the Moon," given before the British Interplanetary Society on 5 March, 1960, at Caxton Hall, London.*

Two schemes for landing instruments on the Moon, top, the "penetration-spike" probe, and below, the vehicle employing storable propellents and a controllable rocket motor linked with a radio-altimeter.

Lunik III

Automation has already been applied most effectively in Russia's first scientific foray around the Moon. Launched by a multi-stage rocket from the U.S.S.R. on 4 October, 1959, Lunik III travelled more than a quarter of a million miles, circling round behind the Moon and photographing its hidden side.

To achieve this remarkable experiment the probe had to be launched with very fine limits of direction and speed. This was done by guiding the launching rocket by radio right up to the time its final stage rocket engine ceased firing. Then the Lunik III instrument container was separated from the last rocket stage and together these two vehicles continued their flight—coasting under momentum towards the Moon.

Tracking stations followed the course of the instrument container by picking up the radio signals it transmitted. When the container had passed the Moon at a distance of 4900 miles it began to loop behind the Moon; and when the probe was directly in line with the Sun and the Moon the process of lunar photography began.

Briefly, the following operations were involved: for purposes of temperature control, the probe was rotating —like a slowly-spinning rifle bullet—as it separated from the carrier rocket. This spin had to be eliminated before photography began by means of external gas-jets.

Next, one end of the probe had to point towards the Sun so that the other end, which contained the camera, pointed in the direction of the Moon. This was done by means of a light-sensitive photo-electric cell which locked-on the Sun while tiny gas-jets, issuing from nozzles on the probe, slowly turned it in the desired direction, permitting another photo-cell to lock-on the sunlit face of the Moon. Thereafter, for 40 min., the gas-jets kept the probe's camera accurately in line with the lunar surface while photographs were taken.

A 35-mm. film camera secured the pictures with automatically varying exposure. The camera had two lenses with focal lengths of 200- and 500-mm., and with their help, pictures were taken on two different scales. The former produced a picture in which the whole of the Moon's disc filled the frame.

After the film had been exposed, it entered a small automatic developing and fixing device. It was then dried and the moisture absorbed to ensure its preservation.

Finally, the film passed into a special case and was prepared for the transmission of pictures, which was accomplished in much the same way as films are transmitted by television stations to our homes.

Two-way communication was maintained with Lunik III's instrument container throughout the flight, and the Earth operator had remarkable control over the vehicle's operation. It was he, for example, who sent the command signal which started the process of photography after the camera had been automatically focused on the Moon. The subsequent photography and processing of the film was performed entirely automatically according to a set programme, but it was significant that radio communication equipment, both in the probe and on the Earth, was duplicated in order to raise the standard of functional reliability. In the event of one component aboard the probe failing, it could be replaced by a reserve component on receipt of a command signal from the Earth station. Transmission of the actual pictures was also triggered by an Earth command signal.

That, briefly, is the story of Lunik III, but it is quite impossible to do justice to this great achievement in a few words. The experiment has clearly shown what can be achieved with automatic equipment if large enough rockets are available for launching it accurately into space.

Soviet Launching Rockets

Let us, then, turn to the rocket vehicles that launched the Lunik probes. The configuration of the final stage of Lunik I was seen for the first time last summer when a full-size model was put on display at the Soviet Exhibition of Science, Technology and Culture in New York.

The final stage was revealed as a cylindrical structure with a conical nose-cap approximately 20 ft. long and 10 ft. diameter. The empty weight was given as 3250 lb.

This model gave one or two important clues concerning the nature of the Soviet launching vehicle which we take to have been an oversize I.C.B.M.—developed before the advent of the dry "light-weight" thermonuclear warhead—fitted with a specially-developed top-stage.

It seems that the final stage contained liquid propellent and that its directional control was achieved by a gimbal-mounted rocket engine. Although the Russians have not confirmed the method of guidance, it seems almost certain that they used a radio-inertial system.

That is to say, the outgoing trajectory of the rocket was rigorously calculated before launching and this trajectory data was then committed to tape. This was then fed into a fast digital computer at the ground base.

When the rocket was launched, several radar stations "locked-on" the vehicle and automatically followed its path. Working together with equipment aboard the rocket they were able to determine its co-ordinates with a high degree of accuracy. The corresponding data, fed into the computer and matched with the taped information, would then detect any deviation from course and would compute, and automatically transmit, the necessary corrective radio commands.

In the rocket's final stage the guidance receiver would then interpret these signals in the form of control functions to ensure that the rocket was steered along the prescribed path.

Returning to the full-size model of Lunik I's final stage, one can see at the base junction boxes which provide interconnection with the lower stage of the launching rocket. It is a fair assumption that these link with a guidance receiver mounted in the top stage for the vehicle's overall guidance and control.

Also on the model one can see that the nose-cap separates along a line just below the windows which have been cut into the cap for display purposes. Inside, one can see the spherical instrument package of Lunik I. Close inspection reveals two small exhaust ports along the separation line, and these are thought to be associated with two small solid rockets which eject the nose-cap.

Immediately above the lettering on the base reading, "Union of the Soviet Socialist Republics—January, 1959," are two VHF aerials. Two communication aerials extend along the sides of the rocket.

Clearly shown are the hold-down clamps, eight of which are used to lock the final stage to the stage beneath.

To the side of one of the VHF aerials can also be seen one of two ejection ports for sodium vapour used to create the artificial cloud which gave Russian scientists visual confirmation that the rocket was on the right course. In her lecture before this Society in February, Professor Alla Masevich said that the only reason why the sodium cloud experiment was carried in the Luniks was to provide visual information that the rocket was in the right place in the sky in case of failure of the radio transmitters.

The firings the Russians made last January into the the Central Pacific Ocean have shown that a new, even more powerful rocket, is being prepared for space-experiments in the U.S.S.R.

Automatic Weather Station

Beyond these experiments lies the prospect of actually landing instruments on the Moon in working order.

If the Moon had an appreciable atmosphere it might simply be a question of bringing the landing vehicle as close as possible to the lunar surface, firing braking rockets at the appropriate point and allowing the probe to drop to the surface using parachutes or some other aerodynamic aid.

I never cease to be impressed by the description of the "Grasshopper" weather stations which the Americans first dropped in the Antarctic during "Operation Deep Freeze" in 1956.

Built in the shape of a bomb, this ingenious device is parachuted from an aircraft on to inaccessible territory to provide on-the-spot meteorological information. The impact of landing sets off a small explosive charge which disengages the parachute and prevents the station from being pulled along the ground.

Then, either immediately or following a pre-set domancy period, another explosive charge causes the station to rise into an upright operating position by means of six spring-loaded legs.

Finally, a third explosive charge extends a telescopic vertical antenna to a height of 20 ft.

The station is then ready to begin automatic transmissions of weather information at intervals predetermined by a built-in timing mechanism.

The "Grasshopper" transmitter has an output of about 5 watts and operates on a frequency of 5 Mc/s.; and it has performed reliably over land ranges of more than 100 miles. The dry batteries used provide power for more than 15 days.

If we had something like a "Grasshopper" station on the Moon, we should be well advanced with our studies of the lunar environment, but, of course, we cannot use parachutes.

As the Moon has, at best, only a very thin atmospheric mantle, any kind of controlled landing must depend on rocket braking and inherent stablizing devices within the probe.

Admittedly, the dropping of a small radio transmitter and a few instruments on to the Moon is, to some extent, facilitated by the Moon's weaker gravitational pull—about one-sixth that of Earth's. Whereas a body dropped on the Earth from a great distance would, ignoring air resistance, hit the surface with a speed of about 25,000 m.p.h., the same body dropped on the Moon would strike at only about 5400 m.p.h.

On the Earth we know that a body falls 16 ft. in 1 sec., 64 ft. in 2 sec., and so on, but on the Moon it would fall only $2\frac{1}{2}$ ft. in a sec. and 10 ft. in 2 sec.

This fact may facilitate a technique whereby protected instrumented packages are ejected on to the Moon's surface from probe vehicles which either make a close approach to the Moon on a grazing trajectory, or from vehicles which actually enter a satellite orbit around the Moon.

A scheme favoured by the National Aeronautics and Space Administration is the gas-cushion which has been devised to absorb the shock of instrumented hard-landings.

The intention here is to eject the deflated probe package by retro-rocket from a probe vehicle passing close to the Moon, and to allow the package to fall unchecked on to the lunar surface.

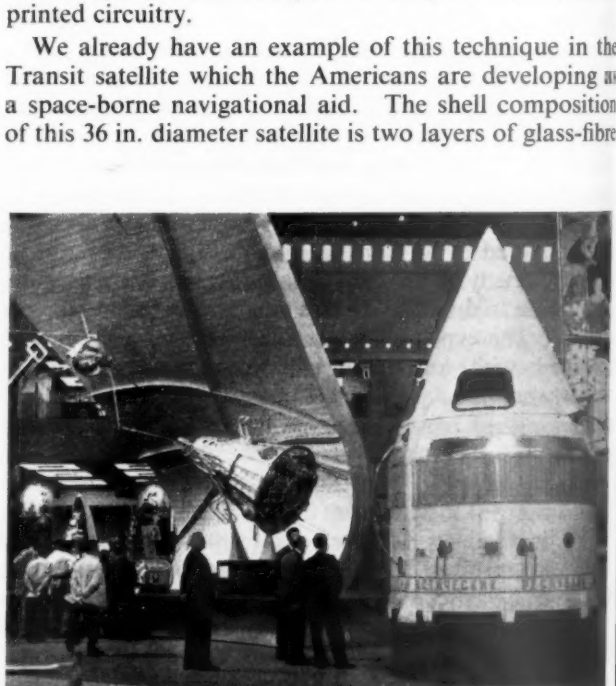
Lightly pressurized with gas on the way down, the cushion would have a robust package of instruments inside suspended from a number of radial cords.

Several cushion structures of this type are being investigated by the National Aeronautics and Space Administration, ranging in size from 5 to 25 ft. diameter. The aim is to produce a cushion whose fabric will compress upon impact with the lunar surface, absorbing the kinetic energy of impact by compression of the gas and by distortion and subsequent rupture of the bag's skin.

The trick will be to allow the cushion to burst at the moment when the instrument package itself touches the surface and so avoid any possibility of the probe bouncing and suffering incidental damage.

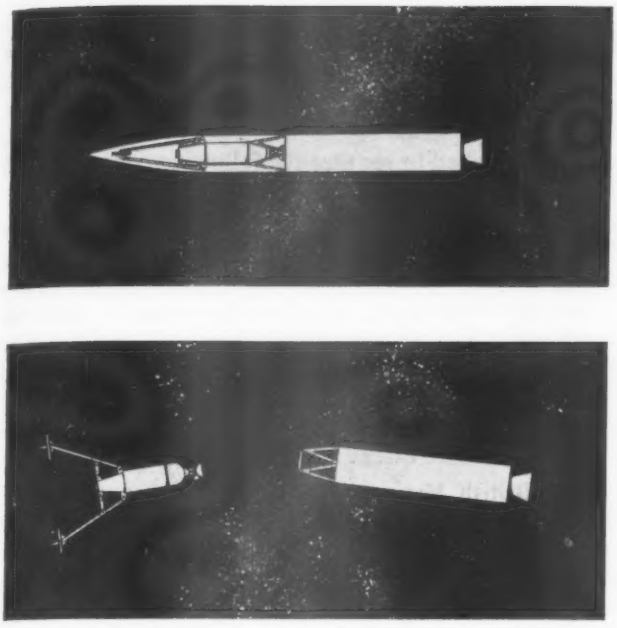
One might well wonder how a probe package of this kind could possibly be landed in the correct attitude to ensure the erection of suitable antenna for the purpose of communicating its findings to Earth. This problem may be solved by painting a helical antenna actually on the surface of the spherical instrument package, in the same way as metal is deposited on plastic material in printed circuitry.

We already have an example of this technique in the Transit satellite which the Americans are developing as a space-borne navigational aid. The shell composition of this 36 in. diameter satellite is two layers of glass-fibre



The size of the Lunik I final stage rocket can be judged from this picture of a full-scale reconstruction on show in New York last summer. Left is a model of Sputnik III.

The Aeroplane and Astronautics



Method of Migrant's arrival, and separation, in orbit around the Moon. The final stage rocket would remain in orbit to act as a repeater satellite for relaying data to Earth.

John W. Wood

with honeycomb structure in between, and broad-band spiral antenna for the three transmitters are merely deposited on the outside.

Crushable structures have also been studied by N.A.S.A. to absorb hard-landings, and indeed similar proposals were made many years ago by Mr. H. E. Ross and the late Ralph Smith.

Soft-landing Instruments

More direct methods of landing instruments on the Moon involve rocket braking and proper orientation of the landing vehicle. Here the requirement is to put down a payload, in one piece, using a minimum of initial vehicle mass. We find that approximately 100 lb of Earth-launching vehicle are required to land 1 lb. on the Moon (*i.e.*, payload plus landing vehicle).* That is to say, for a 100 lb. payload (total vehicle mass, 230–240 lb.) the total mass of launching rocket would be 250,000–350,000 lb.—which, of course, is well within the capacity of Russian launching vehicles.

Undoubtedly the simplest way to achieve a lunar soft-landing is to launch the probe on a collision course with the Moon, as was done with Lunik II.

That is to say, the soft-landing probe will still be fired directly at the Moon's visible face and when it is sufficiently close, a retro-rocket will be fired to "brake" its fall and allow it to land intact.

It may embody a spike which impales the Moon's surface like an arrow, keeping its transmitter and aerials upright, or it may even be fitted with some kind of supporting landing legs. It is here tempting to relate the "Grasshopper" weather station to a braking rocket decent on to the Moon's surface, and envisage a probe which, after making a reasonably soft landing, "struggles to its feet" and begins operating.

In Mr. D. S. Carton's paper, "Minimum Propulsion for Soft Moon Landing of Instruments," presented last year at the Commonwealth Spaceflight Symposium, examples were given for "minimum" probe vehicles using a variety of propellent combinations. The fundamental need is that the combination should be storable from the time of loading on Earth, through the launching phase, and then from 2 to 5 days thereafter. Solid propellents were naturally considered attractive in the case of an elementary soft landing, while hydrogen peroxide, with kerosine, or hydrazine, were considered probably the most favourable of the storable liquids for this application.

Higher-energy combinations would require less mass in the launching vehicle, but they involve difficulties of operation which may considerably reduce the reliability factor of the mission. Thus, a 99·6% peroxide/hydrazine propellent is probably a good compromise, and this offers the further advantage of being a self-igniting pair.

As we have already seen, the Moon can be approached in two ways—either on a hit or miss trajectory. Already we have an example of the former in Lunik II, the 860-lb. lunar probe which crashed to destruction on the Moon on 13 September. Experiments carried by this probe included measurement of temperature and pressure inside the vehicle; instruments to study the magnetic fields of Earth and Moon, meteoritic particles in space, heavy nucleii in primary cosmic radiation and other properties of cosmic rays.

In addition to the radio transmitters used for tracking and telemetry purposes, Lunik II carried a radio-altimeter operating on 183·6 Mc/s. This device enabled a measurement to be obtained of the probe's distance from the Moon during its final approach by the reflection of radio signals from the Moon's surface, and hence it was possible to gauge the probe's acceleration.

It was also considered valuable in relating readings of the Moon's magnetic field on an altitude basis, but as it turned out these were negative.

The important thing, however, is that the Russians have already tested a radio-altimeter in a lunar probe, and are therefore well equipped to pursue the next step in lunar exploration—the soft-landing of instruments.

The precise mechanism of how this will be accomplished is not known but it seems probable that the direct "hitting" trajectory will be chosen for a first attempt. Since a probe vehicle will normally strike the Moon at nearly lunar escape velocity, a retro-rocket is needed to bring the velocity to zero at the moment of contact.

The collision course requires accurate delivery of the carrier, but this has already been demonstrated by the Russians.

* "*Minimum Propulsion for Soft Moon Landing of Instruments*," by *D. S. Carton* (*College of Aeronautics, Cranfield*).

The chief requirements for the probe are as follows:

(1) a retro-rocket, probably a "solid," which will have no thrust-control and no special arrangement of thrust cut-off other than normal end of burning;

(2) a radio-altimeter for triggering the rocket at the correct height above the lunar surface; and

(3) a gyro-reference package working in conjunction with a photocell, possibly locking on to the Sun, to ensure that the rocket is stable in the line of flight before ignition of the retro-rocket. Again, the Russian's have already proved the photocell and orientation technique with Lunik III.

The alternative is to have the probe first enter an orbit around the Moon. Carton had suggested an initial hyperbolic approach, converting into an elliptical lunar orbit, grazing the surface at a mile altitude or less. Landing would then be achieved by reverse-thrust braking on a curved descent path.

This would be a more complex procedure than the direct collision course, being more demanding on propulsion and more rigorous from the viewpoint of attitude control. Possibly here we should use a device which scanned for the lunar horizon; we should also use the storable liquid propellent and a gimbal-mounted rocket motor.

MIGRANT Design Study

In 1958 the British Interplanetary Society published details of a soft-landing probe of this kind which, I am pleased to say, embodies many features which are now being effectively developed by the National Aeronautics and Space Administration in America.

Called MIGRANT from the words Moon, Instrumented Guided Rocket and Notifying Transmitter, the main purpose of the vehicle was to obtain direct surface measurements and to carry out seismic investigations of the Moon's crust and interior.

The vehicle has a landing gear with wide-spread legs and ample travel so as not to damage sensitive equipment. Also, if the vehicle is landed in a predetermined attitude, there is an obvious advantage in the design and installation of research instruments and such systems as temperature control, solar power and data transmission.

In the MIGRANT design, it was proposed to use a radio-altimeter to measure the probe's height above the surface so that the braking rocket would be fired exactly at the right time.

Height would be gauged, as in the case of Lunik II, by the time taken by radio signals to reach the surface and be reflected back to a receiving aerial in the probe. There was also provision for thrust modulation of the braking rocket in conjunction with a miniaturized computer, working together with the radio-altimeter.

In view of the wide experience we have gained in this country with low-thrust, controllable, rocket engines for aircraft applications, it seemed that this was one way in which we might enter into the spaceflight field with the United States in a co-operative programme.

When we visited Amsterdam in 1958 for the 9th I.A.F. Congress, we had an opportunity of discussing these prospects with representatives of the U.S. Select Committee on Astronautics and Space Exploration. In a Staff Report* submitted to Congress in October, 1958, we were gratified to see that the following paragraph had been included:

> "There appears to be a real desire among key British officials to work co-operatively with the United States and to develop British specialities as partnership ventures. It was suggested, for example, that the United Kingdom could build remote controlled probe vehicles for Moon or Mars shots while the United States continued to develop the main boosters. There is sound basis for co-operative action of this type to the fullest possible extent."

The British National Committee on Space Research has subsequently taken up an offer to orbit British-built instruments using an American rocket, the Chance Vought Scout, and there seems no reason why this co-operative programme might not be extended to include instrumentation for lunar and deep space probes, as well as certain specialized types of terminal vehicle.

This, of course, is not to say that in addition we should not develop our own space-boosters, but where opportunities exist for collaboration with other countries it would be extremely short-sighted not to do so.

Descent from a lunar orbit, or from an approach path passing close to the Moon, is essential if we are to investigate the Moon's hidden face. In this case, a point of some importance is that the Moon's mass will effectively block radio signals emitted by the probe and prevent their reception on Earth.

In the MIGRANT scheme provision was made for leaving the final stage rocket carrier in orbit around the Moon. This could then act as a radio-repeater satellite to store data received from the probe on the surface and re-transmit these to Earth during its transits across the Moon's visible face.

Investigations possible with vehicles of the MIGRANT type are varied and range from measurements of lunar radioactivity; micrometeorite frequency; cosmic rays; surface gases, to seismic studies and preliminary analysis of the lunar materials.

A particularly novel investigation concerns seismic studies of the Moon's interior. This would involve carrying down to the Moon's surface a seismograph wired in such a way that it would transmit to Earth coded details of any disturbances taking place in the lunar crust.

Last year two contracts were placed by the National Aeronautics and Space Administration for instruments to probe the lunar surface.

A lunar seismograph to be soft-landed on the Moon within 5 to 6 years is the particular concern of Columbia

* *"Staff Report of the Select Committee on Astronautics and Space Exploration," U.S. Government Printing Office, Washington, D.C.*, 1958.

University and the California Institute of Technology, who are collaborating on its design and construction. With this device it is expected to obtain information on the types of rock present on the Moon, to determine whether parts of the sub-strata are molten, and to investigate the frequency and velocity of meteorites hitting the Moon.

It is considered that a rugged seismometer weighing about 10–20 lb. can be developed, but much, the designers say, will depend on the probe's sinking rate at touchdown, and whether the vehicle remains upright.

Contracts have also been placed with the Naval Research Laboratory for instrumentation to measure the Moon's natural radioactivity, and also for data acquisition and recording equipment.

N.A.S.A. Lunar Working Group

These contracts arose from the formation, early last year, of a N.A.S.A. working group to conduct major long-range scientific explorations of the Moon's surface and environment.

Headed by Dr. Robert Jastrow, the group is one of a number of working units whose members will develop experiments for forthcoming satellites and space-probes.

Experiments being considered by the Jastrow group are as follows:

(1) Probes and orbiters: payload packages designed to obtain information on the lunar environment (*i.e.*, extent of the lunar atmosphere, magnetic fields, interplanetary plasma, fluxes of energetic particles and beta and gamma rays emanating from the Moon's surface).

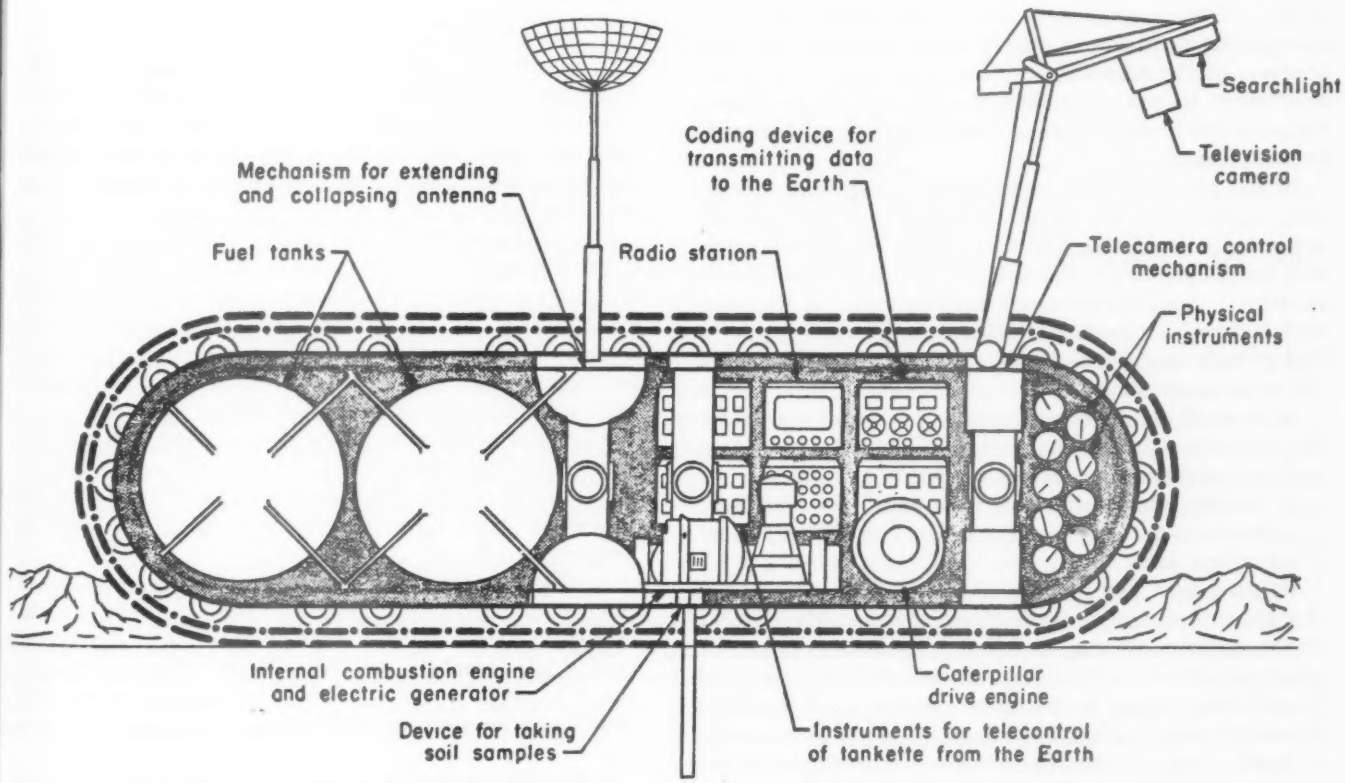
(2) Advanced orbits: satellites circling the Moon and instrumented to give data on the shape and mass of the Moon and the structure of the lunar surface.

(3) Hard landings: instrument packages containing devices such as seismographs and magnetometers to measure properties of the lunar surface. In this case the payload will be packaged to survive impact on the Moon.

(4) Soft-landings: payload packages containing more delicate instruments such as X-ray and T.V. cameras. Braking rockets will be required to land this equipment.

To return to the MIGRANT probe, it was envisaged that if there were no Moonquakes, artificial tremors could be induced by having the probe shoot out an explosive "grenade."

It was theorized that if a number of MIGRANT vehicles were landed the explosion would create pressure waves in the Moon's interior which, recorded by seismographs distributed at various points on the lunar surface, would reveal the thickness of the crust and perhaps discover the nature of the central core.


Searchlight
Television camera
Coding device for transmitting data to the Earth
Mechanism for extending and collapsing antenna
Fuel tanks
Radio station
Telecamera control mechanism
Physical instruments
Internal combustion engine and electric generator
Device for taking soil samples
Caterpillar drive engine
Instruments for telecontrol of tankette from the Earth

Tankette laboratory for lunar exploration, as conceived by the Soviet scientist Yu. S. Khlebtsvich (from *Behind the Sputniks*, edited by F. J. Krieger).

Similar investigations made on Earth during Earthquakes have shown that as the pressure waves travel through the crust, they are reflected in various ways; and from the complicated patterns recorded it has been possible to determine that the Earth is formed of concentric layers of different materials.

It is also possible, at least in principle, to land instruments on the lunar surface which will carry out a certain amount of chemical analysis and telemeter the results back to Earth.

An example was given recently by Dr. Harrison Brown of the California Institute of Technology: "Already," he said, "meteorites are being investigated by X-ray fluorescence; by measuring the number of radiations given off it is possible to determine the relative numbers of atoms of certain critical elements."

If we were able to put a miniaturized device of this kind on the Moon, and compare its findings with those on the Earth, we might be able to obtain an analysis with respect to these elements and in this way determine something about the chemical nature of the lunar rocks.

A more direct approach has been suggested by Joshua Lederberg of the Department of Genetics, Stanford University School of Medicine, although his technique is admitedly more applicable to the investigation of Mars or Venus.

At the recent Cospar Symposium in Nice, Lederberg proposed landing a device consisting of a microscope linked with a T.V. camera. Samples of dust would be fed to the microscope by means of an automatic collecting device. One suggestion is that a travelling ribbon of transparent tape would slowly carry samples past the aperture of the microscope. This may be a fixed-focus instrument with a precalibrated entry slit at the object plane, unless a simple servo-system for optical focusing became feasible.

In the case of micro-biological investigation, Lederberg suggests that the samples might even be fed through preliminary processing baths, including specific enzymes, and specific stains for the detection of nucleic acids and proteins. Also, he envisages impregnation of the tape with nutrient solutions of various compositions; microbial growth on these would then be detected directly on the microscope image.

In view of the processes already developed for Lunik III—the successful transmission of pictures by television, and the automatic processing of film in the probe—one can foresee that further development of automatic equipment on the lines suggested here may not represent a very great step.

Because we know so little about the detail features of the Moon's surface we considered that the MIGRANT probe might even carry sufficient propellent to hover for short periods like a VTOL jet-aircraft and, on command from Earth, would be made to drift for short distances across the lunar surface while its radio-altimeter produced a profile map of the topography. Where the surface was reasonably smooth, within a few feet or so, the probe would then automatically descend.

Obtaining Lunar "Samples"

Other considerations were that, once landed on the Moon to obtain measurements, the probe might embody sufficient reserve propellent to take-off again and return to a close-orbit around the Moon. This, of course, is greatly facilitated by the Moon's relatively weak gravitational field. The landing probe might then be collected by a manned space-vehicle making a circumlunar flight.

In this event, provision would be made for the probe to collect samples of the lunar material for subsequent detailed analysis on Earth. Here it was thought that the probe's feet could be made hollow with automatic shutters for the collection of lunar dust, if such were present, while it did not seem an insuperable problem to have an automatic drilling device which obtained samples from the actual surface.

Yet another application for the MIGRANT vehicle would be that of accurately landing a radio-beacon on the Moon for the close-grouping of supply vehicles prior to the landing of a manned expedition.

Needless to say, the first soft-landing vehicles will be elementary devices by these standards, and it seems unlikely that the first Russian landing probe will embody anything more than a solid retro-rocket and a simple photo-cell/gas-jet orientation system.

However, 5 years ago there is evidence that at least one Russian scientist was already thinking in terms of more sophisticated equipment.

Tankette-Laboratory

In an article, "The Road to the Cosmos,"* Yu S. Khlebtsvich described a device which he called a "tankette-laboratory," a small caterpillar tractor which, having been deposited on the Moon by the last stage of the carrier rocket, would emerge and begin to explore on its own account.

I am sure that when this idea first appeared in print it was regarded purely as science-fiction. After all, no one had yet attempted to launch a small artificial satellite around the Earth and to think of landing a mobile probe actually on the surface of the Moon and, what is more, controlling it by the long arm of an Earth-Moon radio/television link seemed quite fantastic.

The subsequent appearance of the scheme in a Soviet spaceflight film did not help support the scientific case for a device of this kind, and it was not until recently that it has been mentioned again as a serious scientific project.

In December last year, a week before the test-firing of the new Soviet rocket booster into the Central Pacific, the Hungarian news agency M.T.I. stated that the Soviet rocket tests would solve the problem of how to land a robot laboratory on the Moon. Gyoergy Kulin, the Hungarian astronomer, was reported as saying that when

* *Reprinted in English in "Behind the Sputniks", by F. J. Krieger (The Rand Corporation), Public Affairs Press, Washington, D.C.*, 1958.

a Moon-landing is attempted, a caterpillar tractor would emerge from the last stage of the rocket. The tractor, he said, would be able to move up to about 180 miles and would be controlled from the Earth by radio. Television cameras would be used to relay pictures for control purposes.

Despite the high calibre of Soviet achievements in space-research, one may seriously doubt this as an initial project but it was, nevertheless, interesting to hear from Professor Masevich that the tankette-laboratory was one of the methods she favoured for remote exploration of the Moon.

According to Khlebtsvich's original article, steering of the tractor would be facilitated by a boom-mounted television camera having several degrees of freedom. It would be mounted on top of the tankette and would permit the Earth operator to observe the lunar surface immediately ahead and to steer the vehicle by radio command signals. A telescopic self-erecting directional antenna would also be carried on the back of the tankette.

The robot vehicle would also embody tanks for fuel and oxidant to operate the motor for the caterpillar drive and an electrical generator.

Various recording instruments would be carried for measuring properties of the Moon and its environment. One of these would be a soil sampling tube which would be pushed down into the lunar surface at intervals during the tankette's journey. Details of the analysing technique were not given.

Although no precise figures are given for the weight of the tankette-laboratory, the author states that calculation had shown that for a total weight of not more than "several hundred kilograms," serious investigations of the Moon, sufficient for carrying out the next stage—the mastery of the Moon by man—were possible in principle; and it would be possible to land other tankettes, taking into account the results obtained earlier.

Reflecting on the achievement of Lunik III in demonstrating at least two of the necessary techniques involved—direct radio control of operations from Earth, and successful transmission of T.V. pictures over the lunar distance—one begins to realize that the idea is probably not quite as fanciful as it first appeared.

Exploration of the Moon—3

Man on the Moon*

By W. N. NEAT, B.A., A.F.R.Ae.S.

Earlier in this issue of ***"Spaceflight"***, Mr. Moore has given an accurate description of what the surface of the Moon looks like and what we can expect to find when we get there. In another paper, Mr. Gatland has reviewed some of the problems of sending instruments to the Moon (either to go into an orbit round it or to land on its surface) and of what has to be done to get information back from them. By so doing it will be possible to learn far more about the Moon than could ever be obtained merely looking at it through a telescope or by calculating what is possible from the nature of its orbit round the Earth.

This short paper takes the story a few stages further, much closer to its logical conclusion and deals with the reasons for sending man himself to the Moon, together with a discussion of the problems which will first have to be solved with the various benefits which will result when they are.

I must make it clear that this paper does not pretend to be at all original—it merely tries to summarize in a sketchy and somewhat by and large manner some of the information and opinions which have already been published elsewhere, often in a far more detailed manner. In so far as it discusses all the necessary preliminary work, much of which is already going on, the paper does not claim to be in any way an authorative one. It is merely a collection of personal views and thoughts, many of which will be obvious to the reader.

The subject will be dealt with, under three broad headings:—

(*a*) The limitations of merely sending instruments and the reasons for sending men.

(*b*) The many problems involved and how they will be solved.

(*c*) The ultimate possibilities.

Dealing first with the reasons—to begin with, the limitations of automatically operating instruments. It must be admitted that in certain respects instruments possess qualities which men may lack—they have a single mindedness of purpose and are less likely to be put off by their surroundings. They can, for example, be made to operate successfully after having been subjected to high accelerations or to extremes of heat and cold. However, they can only do what they are told and it is not easy by remote control to always ensure they are measuring exactly what was intended. Furthermore, it is no good having instruments going around or resting on the surface of the Moon unless the measurements they take are successfully telemetered back to Earth. Telemetry depends on a number of factors being right and even if they are, the amount of information which can be transmitted in a given time is limited. It may lose

* *Third part of a three-part symposium on "The Exploration of the Moon", given before the British Interplanetary Society on 5 March, 1960, at Caxton Hall, London.*

something in coding and decoding and it may be completely lost, say for example by the premature failure of batteries.

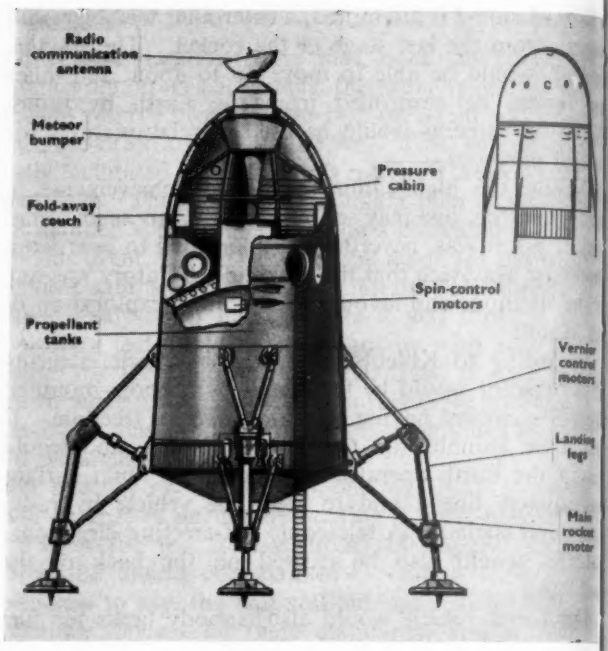
A man, on the other hand, once he can be got there and of course afterwards brought back, can use his measuring instruments to their best advantage. He can adjust them and within certain limits repair them. In addition he can do something which instruments can never do—he can gain a first-hand visual impression of his surroundings and a mental picture to take back with him.

However, to merely do this, is by no means the most important reason for the manned exploration of the Moon. In fact, if it were, then it is doubtful if we should ever go to the immense trouble of sending men at all. Instead it would be found possible, admittedly by a long and painstaking process, involving a great deal of trial and error, to devise instruments which could do nearly all a man could do.

There are, however, other much more valid reasons for manned exploration. The first of these is that the Moon represents a most convenient intermediate step in preparation for the exploration of the planets. This reason is a twofold one—firstly, all the information, know-how and experienced gained in reaching the Moon, landing on it, exploring it and returning to Earth will be vital when we come to the rather more difficult task of reaching the planets and where possible making a landing on them. Secondly, but still in the same connection, it will be far easier to carry out such interplanetary voyages if they begin from the Moon instead of from the Earth. When the Moon is used, in this way, as a sort of stepping stone into space the velocity which such a spaceship has to acquire is then much less than if the voyage were carried out from the Earth's surface. It is obvious, however, that such a manoeuvre cannot even be considered until the Moon itself has been safely reached and man firmly established on it.

Another long-term reason for reaching the Moon is to actully take advantage of the admittedly inhospitable conditions existing there. As examples of this, the lack of an atmosphere and the reduced gravitational force will provide unique opportunities and advantages for the astronomer and physicist.

In addition to these valid practical reasons, there is an underlying fundamental justification for going to the Moon. This may be influenced by considerations of national prestige or even thoughts of military advantage, but basically it can be said that as long as the Moon is there to be reached by man and as long as he can foresee possible ways and means of getting there, then sooner or later attempts will be made. It is, to some extent at any rate, the same argument that prompted Colombus to sail off into the unknown to discover the Americas, except that in the case of the Moon we are quite sure there is a target to be reached, whereas Colombus only thought there was. From another point of view, a comparison can be drawn with recent expeditions into the South Polar regions. These regions exist, there are data to be determined from them and therefore man goes to explore them.



Drawing by John W. Wood of a man-carrying lunar landing vehicle, based on designs by the late R. A. Smith, past chairman of the B.I.S. Top right is the design produced by a B.I.S. Technical Committee in 1938.

Let us now consider the problems which have to be solved before any manned exploration is posible. At this stage, it must be made clear that these problems can only be overcome by a long and expensive process of logical steps each one getting a little more difficult than that preceding it. In this chain of events, the setting up of unmanned satellites is an important stage, the landing of instruments on the Moon another. Let no one imagine that instrument landings are an alternative to manned exploration; in actual fact, such achievements are an essential part of preparation for manned landings. This is because getting instruments on the Moon will not only provide the moral encouragement for the first manned flight, but will also provide the necessary background of technical information relating to space between the Earth and the Moon and of the Moon's surface itself, together with vital information necessary to effect a successful landing on it.

The main problems to be solved are as follows:–

(1) The acquisition of the necessary velocity.

(2) The technique of landing on the lunar surface.

(3) The technique of getting back to the surface of the Earth.

(4) The provision of a suitable environment for the occupants during the voyage.

(5) The provision of means to explore the Moon's surface.

(6) The selection and training of personnel.

These will now be dealt with, one by one—to begin with, the acquisition of the necessary velocity. The fundamental difference between landing instruments on the Moon, and making a manned voyage, is that for the latter, a return has to be made. This sounds like overstating the obvious, but its importance cannot be overemphasized. To take off from the Moon's surface and to land back on the Earth both demand the use of rocket engines and these require propellents which all have to be carried up from the Earth's surface somehow or other. The effect of having to do this on the launch weight of the rocket vehicle concerned and therefore, on the magnitude and cost of the project is very considerable.

Let us put the comparison into perspective; this can best be done by considering the velocity changes (the acclerations and the decelerations) which are required during the voyage. Fortunately these individual velocity changes can be added up regardless of whether they are positive or negative and the total represents the amount of propellent which is needed. For soft landing instruments on the Moon a total velocity change, making a rough and ready allowance for air resistance and gravitational losses, is about 15 km./sec. Assuming conventional propellents such as liquid oxygen and kerosine and three stages each with a structural factor of 0·10, then 100 lb. of instruments can be put on to the surface of the Moon for a launch weight of about 150 tons, not an unreasonable figure.

However, let us now consider sending a man to the Moon and getting him back. The velocity change requirement is then twice as much, namely 30 km./sec. Let us, however, assume that aerodynamic braking is used on return to the Earth and with some other refinements such as that of carefully choosing a minimum energy path for the journey, reduce this to 25 km./sec., the very minimum which can be considered possible. If three stages and the same structural weight factor of 0·10 are assumed, it can be deduced that with oxygen and kerosine as rocket engine propellents it is quite impossible to put any payload at all on the Moon and get it back again.

Even if the very best performance possible from chemical propellents is assumed, and the structural factor reduced to 0·05 (quite an ambitious figure) one still finds it requires a take-off weight of between 700 and 1100 tons (depending on whether five or three stages are used) for every ton of payload taken to the Moon. Bearing in mind that this payload must include not only the men in their capsule, but the instruments they carry, together with whatever landing device is necessary to permit a safe landing on the Moon as well as a parachute or wings to permit the final landing back on the Earth, it can be seen that the use of chemical rockets in this way only marginally permits a lunar landing, if it can be said to permit it at all.

What then are the alternatives? They are either to use an atomic rocket or to begin the lunar voyage not directly from the Earth's surface but from an orbit round the Earth.

If an atomic rocket is used, and especially if it can be used not only for the take-off from the Earth's surface but also for the subsequent return from the Moon, then its increased exhaust velocity will without doubt enable increased payloads to be carried. However, before such a rocket engine can be used two conditions have to be met. Firstly, the weight of internal shielding must not be so great that it eats away the payload, and secondly, it must be established that the efflux does not irrevocably contaminate the take-off areas.

Let us now consider the other alternative of beginning the voyage from an orbital path. Because when beginning its voyage, the ship already has orbital velocity, the total velocity change subsequently required for this manoeuvre is comparable with that for a soft instrument landing, namely, about 15 km./sec. Assuming that high energy chemical propellents, an advanced structural factor of 0·05 and three stages are used, the initial weight required per ton of payload is a mere 50 tons, a most remarkable reduction.

This initial weight would be even more reduced if an ion rocket were used for acceleration away from the orbital path and for deceleration again back into it or if a higher thrust atomic-powered rocket were used for the landing and return from the Moon's surface. However, as stated earlier these propulsive methods could only be used advantageously if shielding problems were solved and if contamination levels were acceptable.

What, then, is suggested by the above considerations? Primarily, that if chemical propellents are used and possibly even if nuclear propulsion is employed, manned voyages to the Moon are more likely to begin not directly from the Earth's surface but from an orbit around the Earth. Otherwise the initial weight of the vehicle becomes prohibitively great, and while this may just be accepted for a few expeditions this is hardly likely to be the case when voyages become more frequent.

This presupposes that prior to such attempts at lunar exploration, the technique of establishing Earth satellites will have greatly advanced. The need to begin a lunar voyage from an orbit round the Earth does not necessarily imply that the voyage must begin from a large satellite established there. The lunar ship itself may be established in its orbit having used up all its propellents getting there. It is then replenished from other rockets sent up from Earth to rendezvous with it. This implies a great advance in guidance and navigational methods as well as an improvement in the reliability of the individual components making up the complete operation.

Even if chemical rockets are used, notable advances in their design will be required, particularly with regard to the high energy propellents which must be used. At the same time, these engines will have to be developed so as to be capable of repeated use in order that the various operations, each separated by a few days, can be successfully carried out. This implies the ability to restart a number of times with no attention in the meantime. In addition, in order to permit the delicate manoeuvre of landing on the Moon, the rocket engine used will have to

be capable of variable thrust, fully adjustable with a high rate of response.

Also implied is a considerable decrease in structure weight. This can be obtained largely by the use of advanced very high tensile strength materials and, what is probably even more important, the development of novel methods of design and construction. It may be possible to exercise a great deal of ingenuity in not only making parts of the structure light, but also in making them serve more than one purpose. For example, the undercarriage for landing on the Moon could become the wings used for landing back on the Earth.

Let us now deal with this technique of landing on a lunar surface. This will be done by slowing up the rocket so that it is captured by the Moon's gravitational field, and falls toward its surface. The use of rocket engines to finally retard it will be delayed for as long as possible in order to economize the use of propellents. The whole process at this juncture will be completely automatic, using an approach radar or similar system which decides exactly how much rocket thrust is needed and when it must be applied. Variable thrust will be necessary and its control must be exact and almost instantaneous. After being initially orientated in the correct position by means of small vernier rockets, the ship will probably be stabilized during the powered part of the descent by gimballed thrust chambers as used on current large missiles. Otherwise the vernier rockets may be used for this purpose.

However fine and effective the control of the rocket engines is, there is likely to be some residual velocity left which has to be absorbed on landing. For this a sort of undercarriage will be necessary. If the ship had originally come up from the Earth's surface this would have to be retractable. Otherwise (and which is more likely) it could have been fitted when the ship was in its earthly orbit being refuelled.

The requirements for such an undercarriage are quite exacting. To begin with, it must be very light and still capable of absorbing quite a lot of energy. Secondly it must be capable of effective operation on an unknown and possibly irregular surface, since it is very doubtful that it will be possible to choose the landing point with pinpoint accuracy. Finally, it must be capable of stabilizing the ship in the correct attitude for its subsequent take-off.

It is fortunate that the whole process of a lunar landing can be closely simulated by controlled experiments close to the Earth's surface. There are two influencing factors which cannot, however, be reproduced exactly. One is the difference in gravitational force on the Earth as compared with the Moon, but this can be allowed for. The other is the absence of an atmosphere, the effect of which at low speeds is small. One can easily imagine a series of such experiments, first of all with a vehicle taking off, rising a few feet and then landing again. Gradually the height will be increased and later the experiments will be extended to include orientating the missile from a horizontal to the vertical position required for landing. These tests will simultaneously develop the three unknowns in this operation, *i.e.*, the automatic land approach system, the control of rocket engine's thrust both in magnitude and direction and the landing undercarriage.

Having briefly dealt with the question of the actual landing on the Moon let us consider that of landing back on the Earth's surface. This problem will incidentally be with us well before a lunar voyage is attempted since as soon as a manned satellite is established some means will be needed for getting men safely back from it. The problem of recovering men from a satellite is almost exactly the same as that of recovering men who have been to the Moon.

Two methods, or a combination of the two, would appear to be possible. The satellite or the ship returning from the Moon will first of all be slowed down by the use of its rocket engines. This will be done to enable it to enter the upper layers of the atmosphere very gradually. Atmosphere drag will then slow the ship even more but in consequence heat will now be generated. This will be dissipated either by internal cooling or by fitting the ship with rudimentary wings so that when it gets too hot it climbs to a higher altitude where the air is thinner, losing both speed and heat by radiation at the same time. By a gradual controlled process of this sort, it may be possible to judiciously use the atmosphere as a braking force so that eventually the ship, nearer the ground with the greater part of its speed lost, can be brought down through the denser atmosphere layers using wings or a parachute. Of the two, the parachute appears the most feasible since it would give a greater chance of a successful landing regardless of the terrain.

Experiments to establish these techniques or at least to provide information to enable them to be done, are already under way. The X15 aircraft will approach the condition of a completely winged landing. During another series of experiments it is intended to recover the Mercury capsule by parachute. In solving these problems, all the work which is being done on the re-entrant problem of missile warheads will be of great value in deciding how the problem of kinetic heating can be best overcome.

Let us now consider the problem of providing a suitable environment for the personnel who will undertake this lunar voyage. To a great extent this problem, like that of landing back on Earth should have already been solved, because it will apply almost equally to the manned satellite.

The requirements are:—

(1) Heat and light.

(2) Oxygen, water and food.

(3) Means to resist high acceleration and weightlessness.

The question of heat and light should not be a great problem. The development of more efficient chemical batteries, solar batteries or fuel cells should provide all

that is required, not only for personnel themselves but also for radio and the other automatic devices which will need to work during the voyage.

Both oxygen and water are amenable to recovery processes and virtually no-loss systems can probably be worked out. Whether they will be necessary for early lunar voyages is doubtful and can be determined only by a detailed project assessment. If they are necessary then their operation can be completely worked out on the ground beforehand.

For the first few lunar voyages it is unlikely the question of food will prove very difficult either. In any case, all the physical effort likely to be expended on a lunar voyage can be simulated beforehand with reasonable accuracy, energy balances work out, and the correct amount of nourishment in its most convenient form determined.

With regard to the high accelerations obtaining during certain periods of the voyage, much is now known about the amount of acceleration which the human body can stand and how its effect can be reduced by adopting a suitable attitude with adequate support. It should be borne in mind that during a lunar voyage and especially when under high accelerations, the voyagers will have very little to do. It is likely that the same conditions of comparative inactivity will also apply during the remainder of the voyage and this may affect what has to be done to combat weightlessness. In any case, experience with aircraft like the X15 and other near satellite projects will indicate how serious or otherwise this problem really is.

The problem of environment cannot be divorced from that of the personnel themselves, and their selection for the initial lunar expeditions. There is unlikely to be any shortage of volunteers, but selected personnel will not only have to be physically fit, but they will also have to be psychologically suitable. The Armed Forces would appear to be the most suitable recruiting grounds, in the early stages, at any rate, largely because there will be found men of the right physical and mental standard, technically trained and who have been subject to the required discipline, discipline which will not only be necessary during the expedition itself but also during the months and years preceding it.

Selected personnel will be subjected to a period of training and conditioning, *e.g.*, in centrifuges and in special containers designed to simulate as exactly as possible the environment to which they will be subjected in space. This process itself will result in some further selection and possibly elimination. Those left will be given further training in aircraft like the X15, in projects such as Mercury and Dyna-Soar, and finally in manned satellites remaining in orbit for varying periods of time. During this time they will carefully study all aspects of their eventual rôle, the machinery and equipment they will use and the conditions and emergencies they may have to face.

Their ultimate goal will, of course, be to reach and walk about on the Moon's surface. For this suitable suits will have to be developed, a process which can quite conveniently be carried out in the laboratory since all the environmental conditions of airlessness, heat and cold which exist on the Moon can be simulated. The one which cannot conveniently be is that of gravational force, but once again allowances can be made for this.

The requirements for such a suit are that it should be light in weight, not because of any particular difficulty to the wearer (bearing in mind the low gravity on the Moon) but rather because it will have to be carried in the ship where every pound of weight will be at a premium. It will have to provide protection either against the heat of the day or the cold of the night and, of course, it will need its own oxygen supply. Preferably it should carry its own short range radio equipment so that its wearer can maintain contact with his fellow explorers and with the ship from which he has wandered. Still affording complete protection, it must permit its wearer a certain amount of agility, giving him the ability to pick up and carry things, adjust instruments and so on. Although the conditions are exacting, no insuperable problems are likely to be involved. They can be overcome by the development of techniques already established for high altitude pressure suits and the like.

Let us now project our minds forward a number of years and assume that all the preparatory work which has just been described has been successfully accomplished. Let us also assume that the technique of establishing Earth satellites has progressed and that large satellites can be established in far more predictable orbits. The scene is now set for man's first visit to the Moon.

Assuming this begins from an orbit around the Earth, the voyage will take 4 or 5 days, the exact time depending on the particular path in space which is chosen. On nearing the Moon the ship will be correctly orientated and then retarded so that it falls towards the Moon's surface. In the way already described, the final braking will be done again using the main engines, the whole process being automatically controlled.

The site for a landing will have been chosen as accurately as possible beforehand. This will have been done by a detailed examination of photographs and pictures telemetered back to Earth by the many unmanned instrument voyages which will have, by then, been previously made.

It has been suggested that when the first lunar travellers arrive they will find, already on the surface of the Moon, a ship very similar if not identical to their own. This will have been sent up beforehand and it is possible that no manned voyage will be attempted until an unmanned ship has been successfully landed. Since, even when men are on board, the complete landing procedure will be automatic, the robot ship will not present any greater problem. Its accomplishment will serve two purposes. Firstly, it will establish a satisfactory techniqe demonstrating that a suitable landing place has been found. Secondly, it will provide a spare vehicle, should the man-carrying vehicle be damaged in landing and not capable of bringing the voyagers back to Earth.

The first sojourn on the Moon is unlikely to last more than a few days. The time of stay will be accurately determined beforehand as indeed will be the entire outward and return voyage. On their first visit the explorers will not go very far from the ship that brought them there. During their brief stay, however, they are likely to be very active securing as many measurements as they can, taking photographs and collecting geological specimens.

This first brief visit will be followed by other visits of increasingly longer duration. During these, simple portable shelters will be set up, probably kept in shape by the air used to inflate them. Not only will such shelters provide a breathable atmosphere, but will also protect their occupants from the cold of the night and the heat of the sun.

As more and more area of the Moon is to be explored some form of transportation will be required mainly for carrying instruments and equipment from one part of the landing site to another or to parts of the Moon which it is intended to explore. It must not be forgotten that the process of both movement and carrying will be eased by the low lunar gravity. On the other hand, it will be aggravated by the uneven terrain, the sheer precipices and deep fissures which are likely to be found.

As soon as it is possible to spend anything longer than a few days, the question of power supplies will arise—power for heat, light and radio. It is possible that the Sun's rays will be used for this, but it is to be hoped that by this time some form of small portable nuclear source may be available.

It can be envisaged that within a few decades or so of the first landing, permanent encampments will be set up. These will be partly built by materials sent up from Earth by unmanned rocket vehicles but it is not an unreasonable hope that most of the material for their erection will be found on the Moon itself.

Eventually one can imagine such encampments, built for heat insulation purposes partly below the surface, to be completely self providing. Each will be equipped with an air replenishing and purification plant, a water reclaiming plant and a food supplying plant where vegetables are grown under highly productive conditions. With such facilities, it is conceivable that any deficiencies can be made up from the minerals to be found on the Moon itself.

These encampments will contain laboratories where experiments can be carried out under low temperature and higher vacuum conditions than it is easily possible to obtain on the Earth itself. The low gravitation effect may be used for other experiments. Observatories will also be set up, advantage being taken of the Moon's lack of atmosphere to increase our knowledge of the more distant galaxies and constellations.

In this short paper the possibility of permanent centres of habitation is left to the reader's imagination. However, even a short paper would be incomplete if further mention were not made of the use of the Moon as a stepping stone into deeper space. Much has been written and mathematically proved to show how useful Earth satellites will be as such stepping stones. In fact, this paper earlier endeavoured to show how effective an Earth satellite (or at least the ability to set one up) will be in helping us to reach the Moon.

Now what is the Moon but a large stable Earth satellite already provided for us? Inhospitable in many ways it may be, but there is no reason why its uncongenial conditions cannot be sufficiently overcome.

Because of its low gravity and lack of an atmosphere, it can be quite easily shown that when considering interplanetary voyages, from the point of view of the amount of rocket propellents which have to be carried and therefore the sheer size of the ship needed to carry them, it is advantageous to begin such a voyage from the Moon and not directly from the Earth itself.

While the first of such voyages is most likely to begin from an orbit around the Earth, I think it is equally likely that when much larger payloads have to be transported (such as, for example, when an encampment is being set up on Mars) it will prove better to assemble such a payload on the Moon, once man has been firmly established there, and to use a lunar base as a take-off point.

WANDLESIDE WARREN WIRE CO. LTD.

Are Specialists in the manufacture of Electric Wires and Cables, for **REALLY HIGH** TEMPERATURE APPLICATIONS for all Electronic Devices as used in Space Vehicles, Rockets, Guided Missiles, etc.

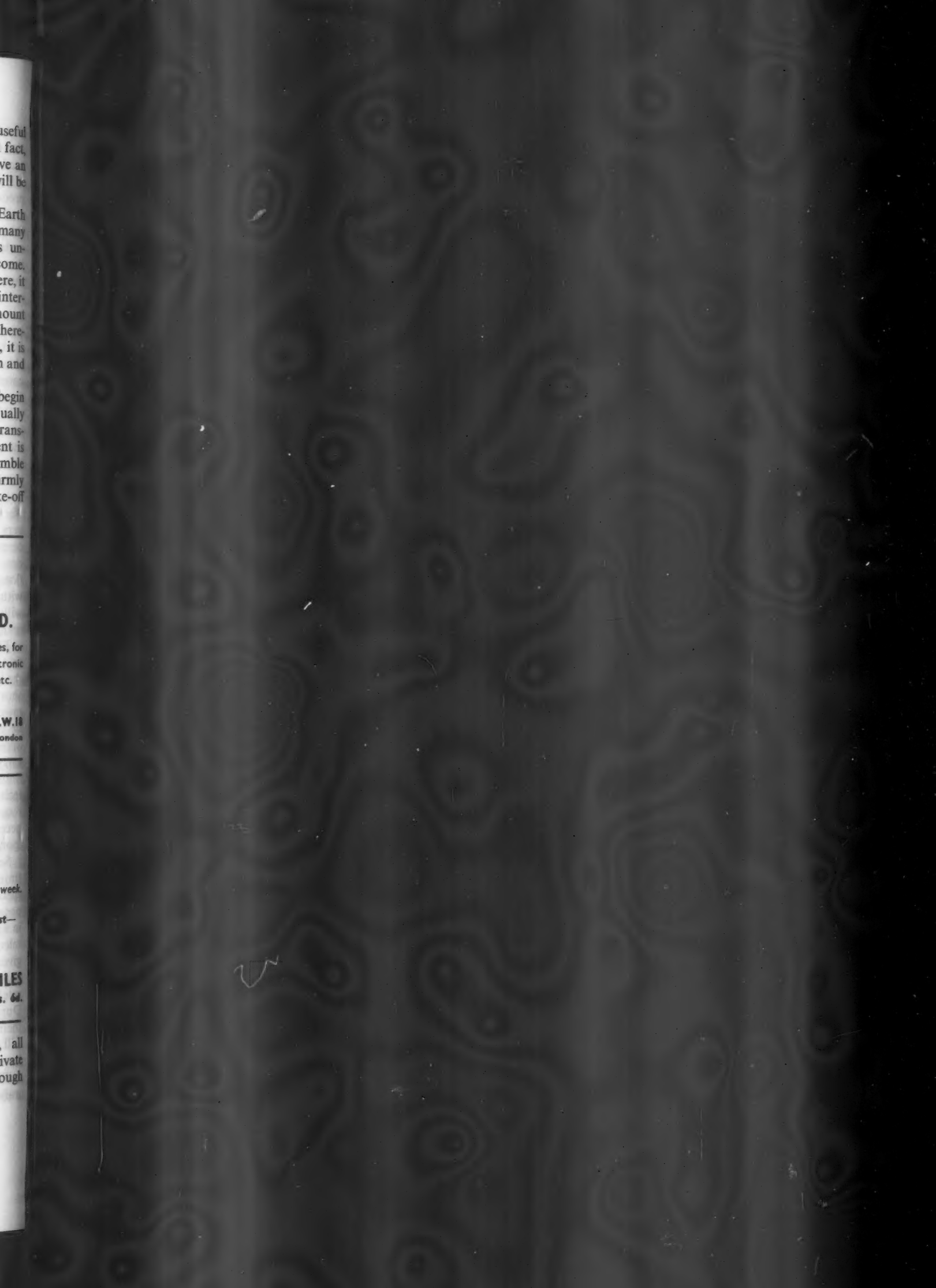
All enquiries to:—
106 GARRATT LANE, WANDSWORTH, LONDON, S.W.18
Tel: VANdyke 7544 **Telegrams Wandleside Put London**

The first weekly Space survey . . .

First aviation weekly to introduce a regular spaceflight section, FLIGHT is first choice for all who look for up-to-the-minute, superbly illustrated news coverage of astronautics—and missile—progress the world over. Read it, every week.

FLIGHT *First—and foremost—of the world's aviation journals*

AIRCRAFT · SPACECRAFT · MISSILES

From all newsagents: **Every Friday 1s. 6d.**

WANTED—Rocket mail stamps and covers, all countries, single items or small collections, by private collector. Write c/o Box No. 55, BIS, 12 Bessborough Gardens, London, S.W.1, England.